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Otsuka et al.

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(54) **CENTRIFUGAL FAN**

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F04D 29/30 (2006.01)

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CPC ***F04D 29/666*** (2013.01); ***F04D 29/281*** (2013.01); ***F04D 29/30*** (2013.01)

(58) **Field of Classification Search**
CPC F04D 29/666; F04D 29/281; F04D 29/30; F04D 29/326; F04D 29/329;
(Continued)

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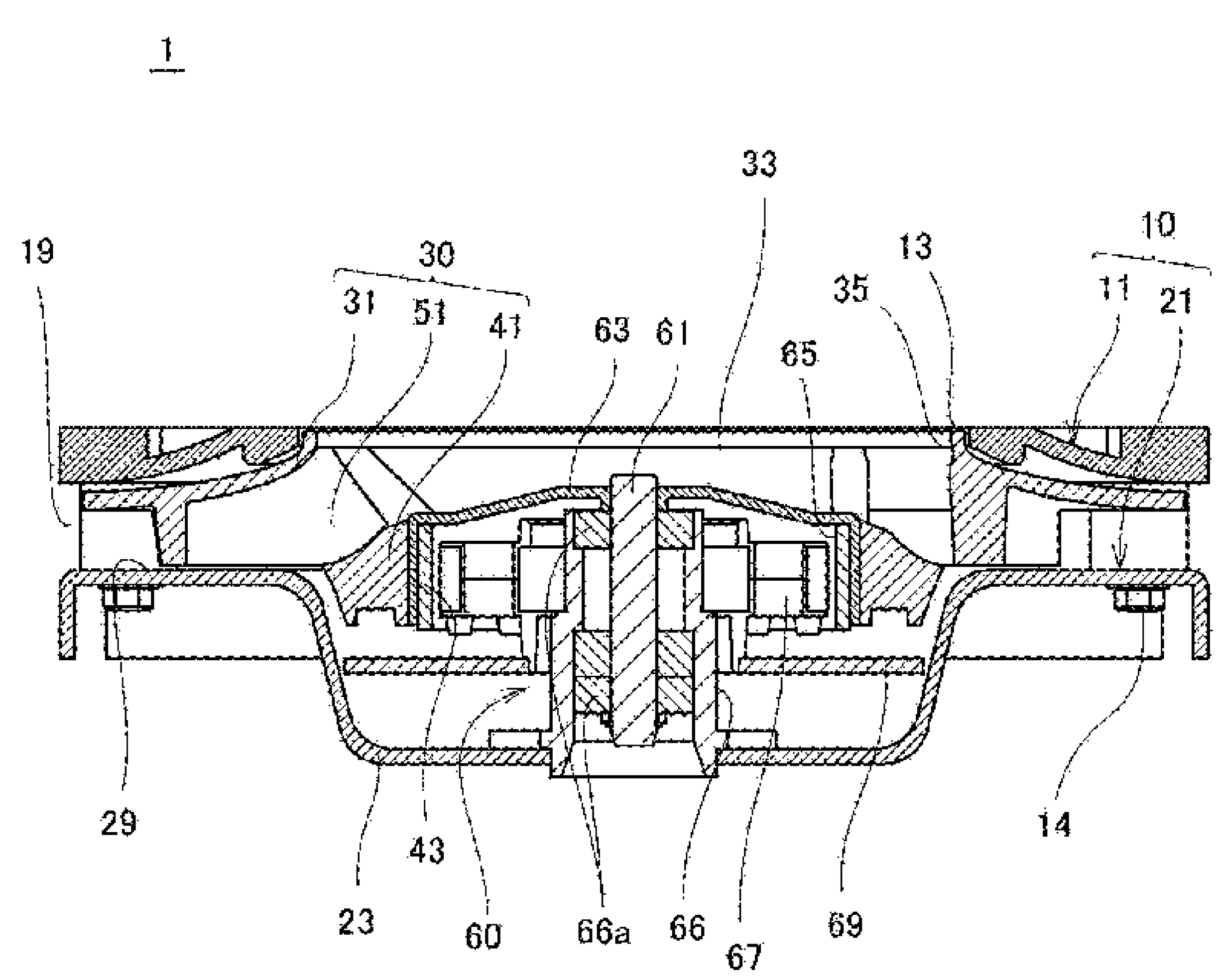
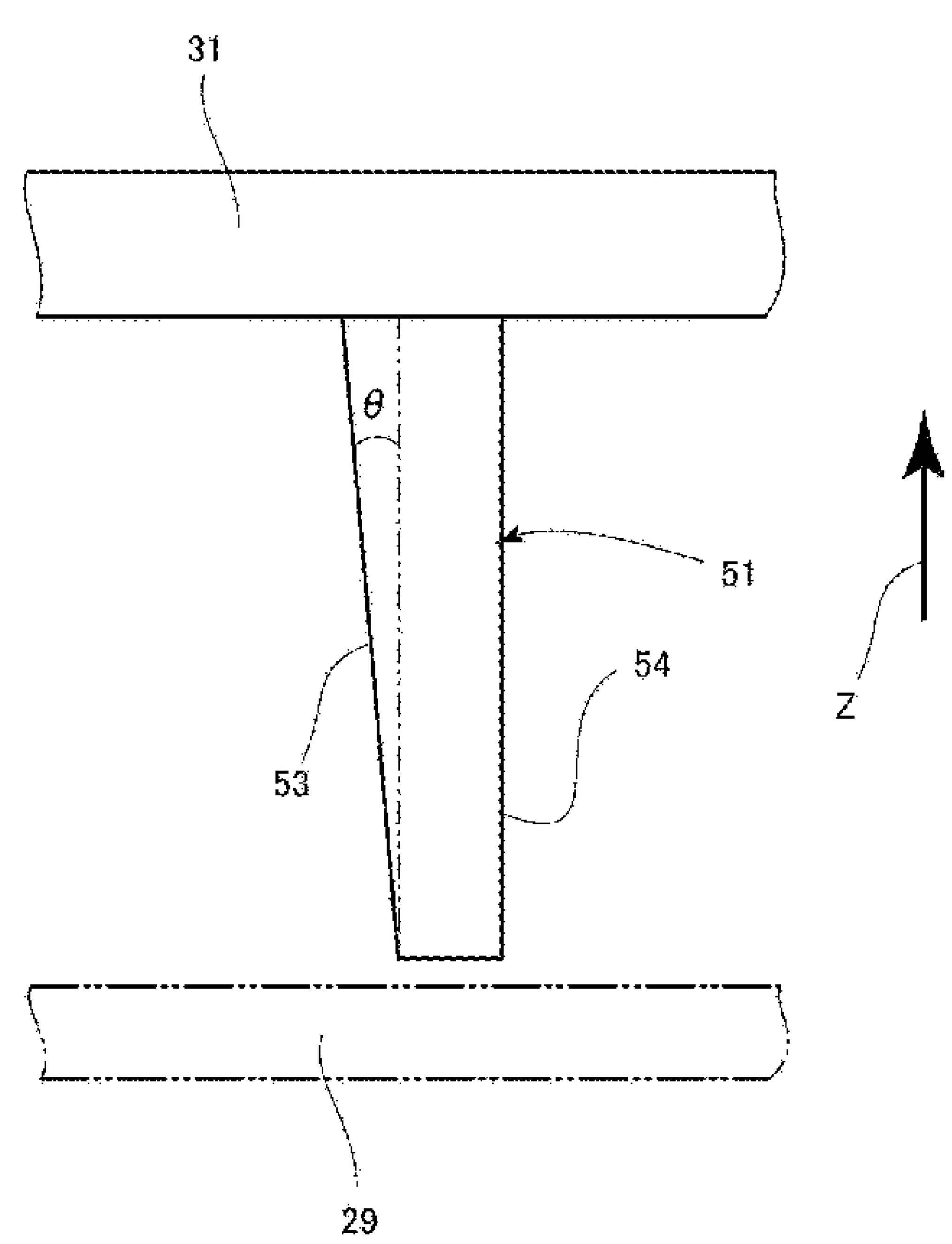
(57) **ABSTRACT**

A centrifugal fan includes an impeller, and a lower casing provided below the impeller. The impeller includes an upper shroud having an upper portion formed with an inlet, a lower shroud, and a plurality of blades arranged along a circumference direction between the upper shroud and the lower shroud. The blades extend from an inner side area to an outer side area in a radial direction, and are only connected to the lower shroud with the inner side area such that at least an outer circumferential side portion of each blade faces an upper surface of the lower casing. A surface of the lower casing, which faces the impeller, configures a portion of a wall surface which guides the fluid introduced from the inlet. A surface of each blade at a side of a leading edge portion is formed with a discontinuous portion having a step shape.

15 Claims, 24 Drawing Sheets





(58) **Field of Classification Search**
CPC . F04D 29/384; F04D 25/064; H05K 7/20136; H05K 7/20172
USPC .... 361/678, 695; 416/181, 210 R
See application file for complete search history.

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FIG.1

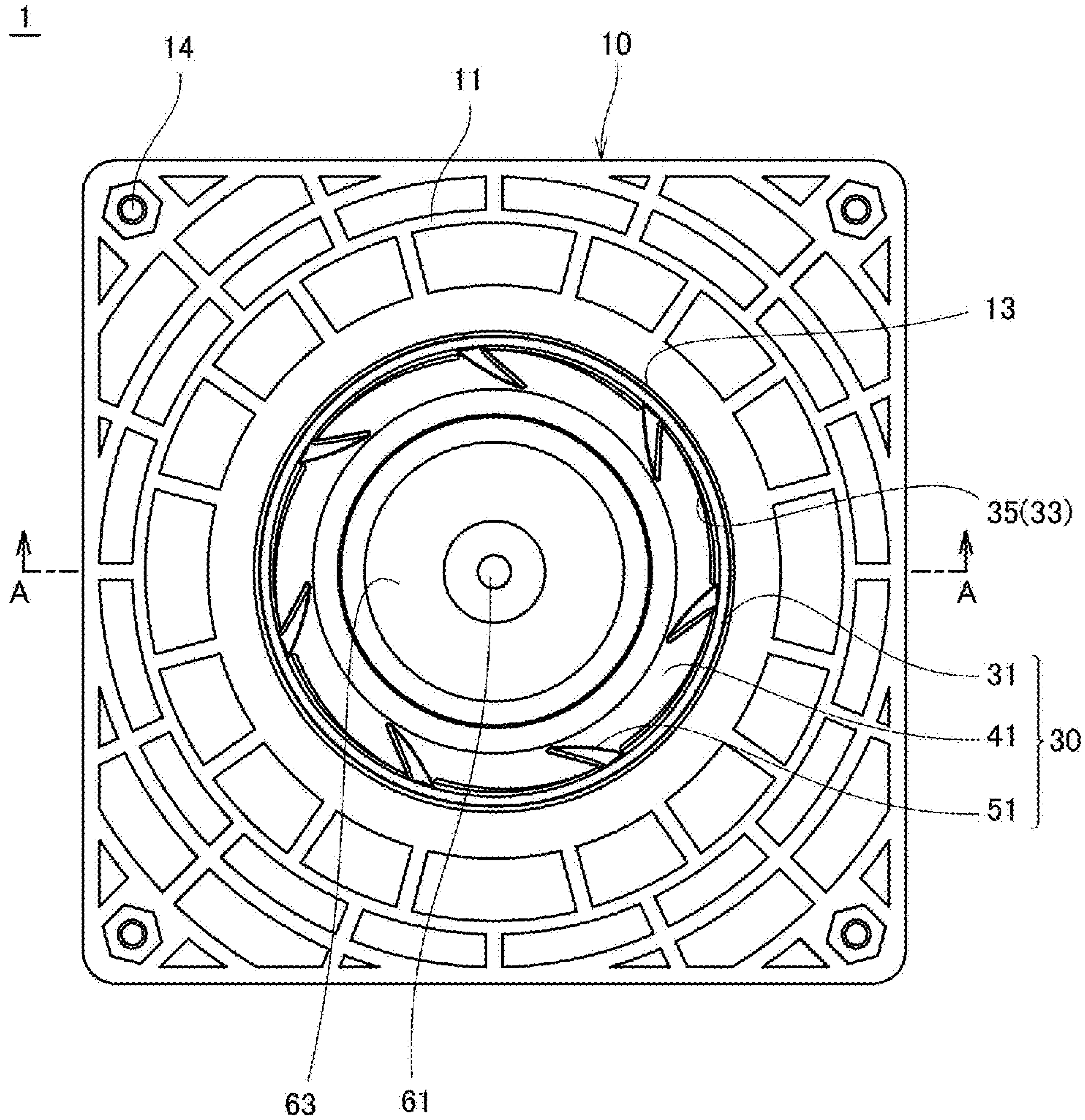


FIG.2

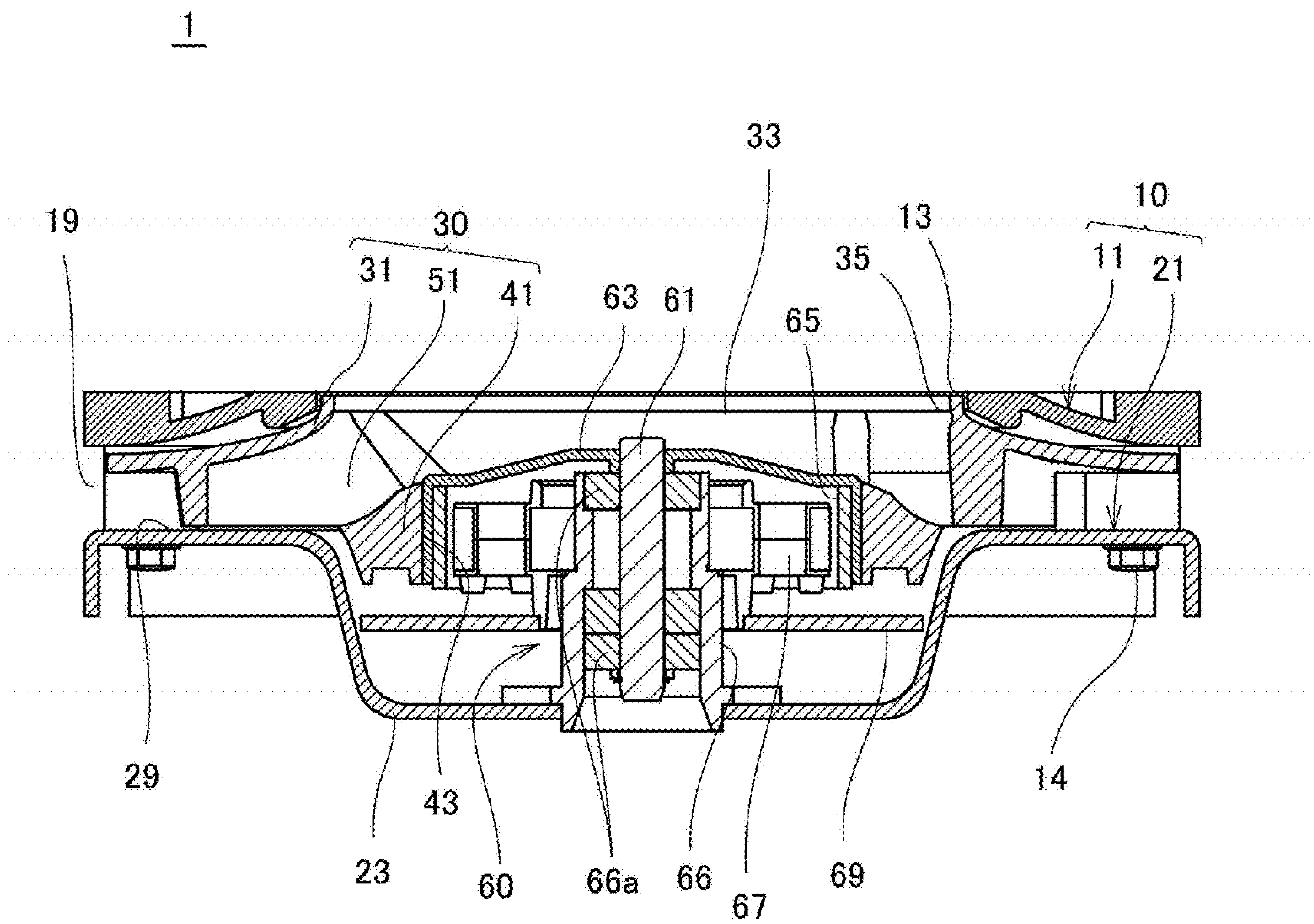


FIG.3

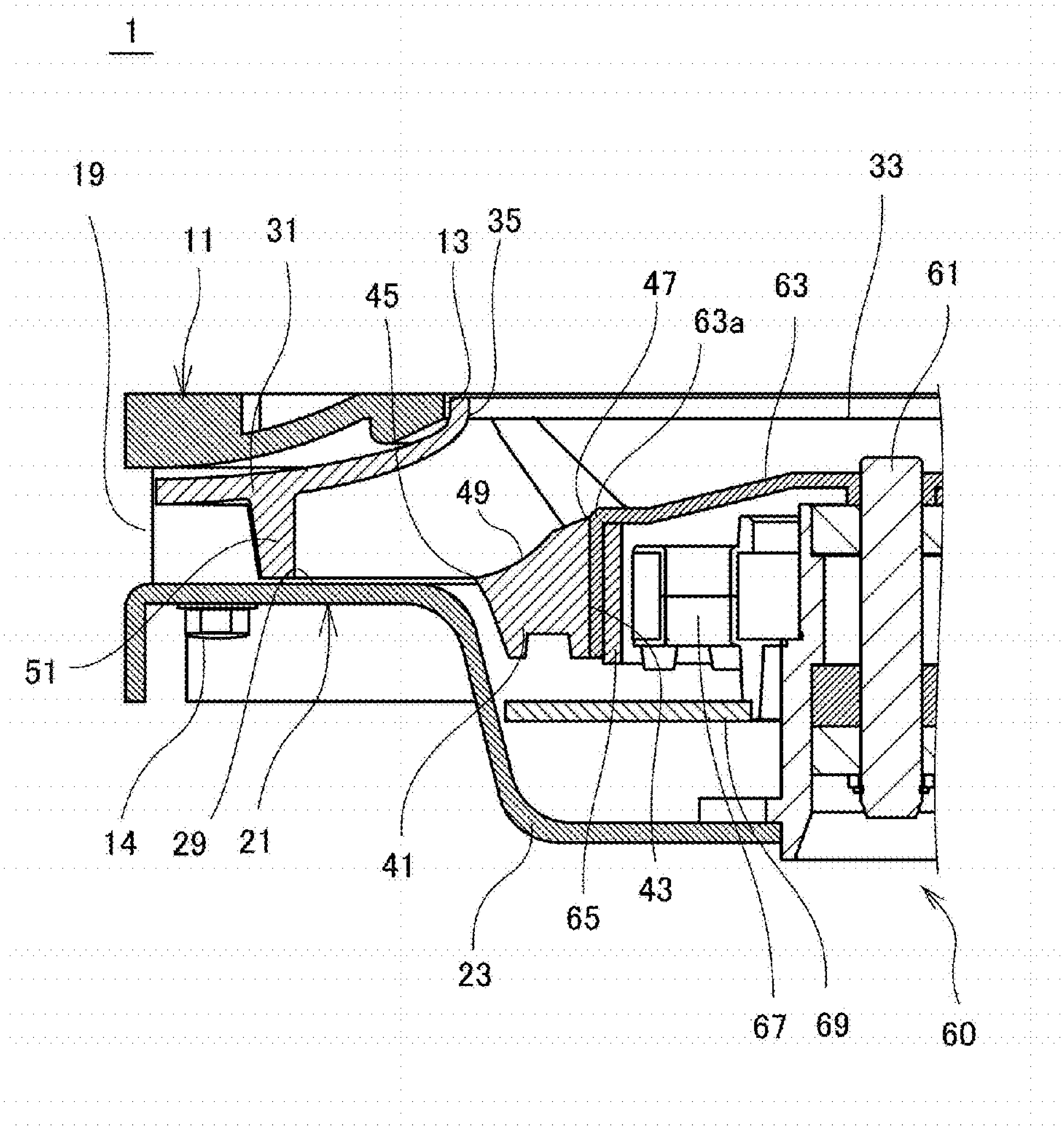


FIG.4

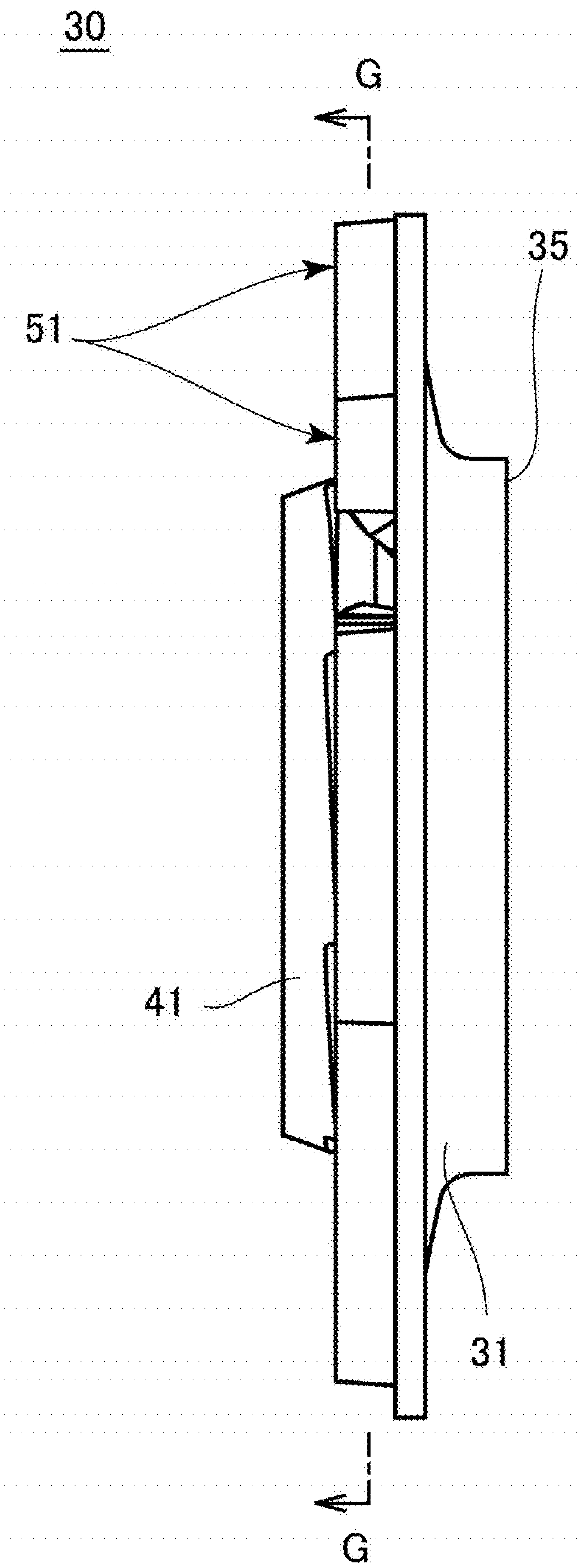


FIG.5

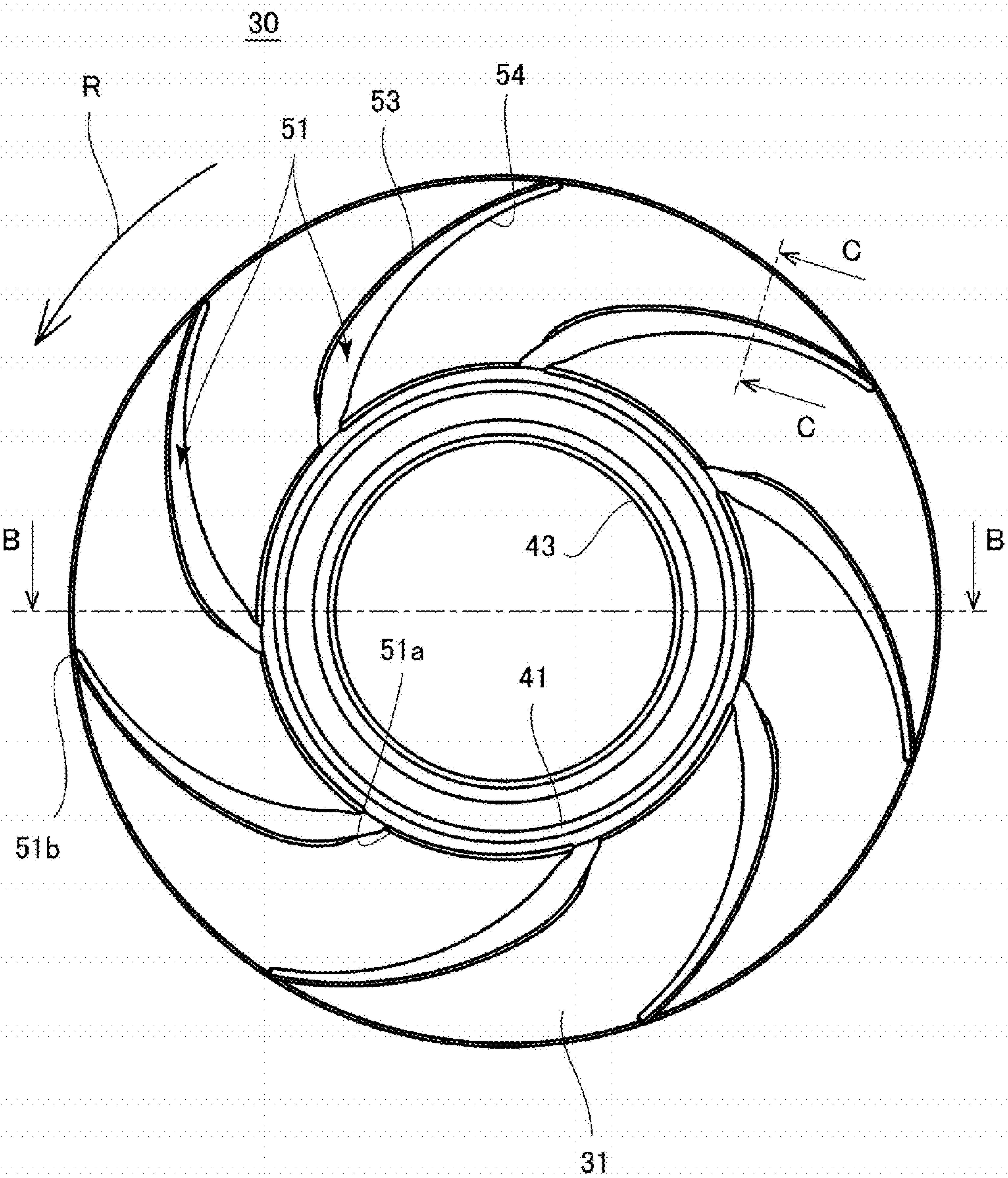


FIG.6

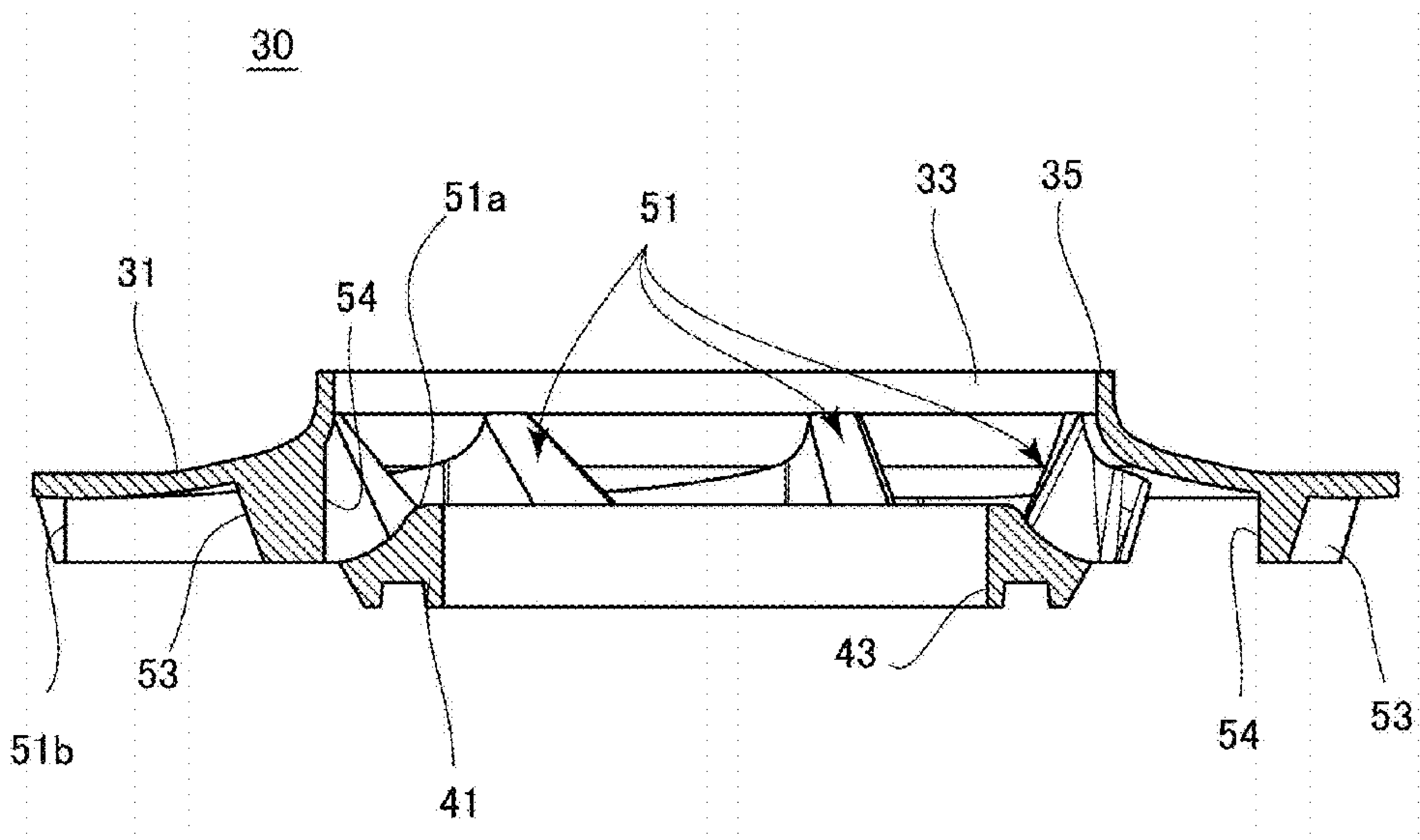


FIG.7

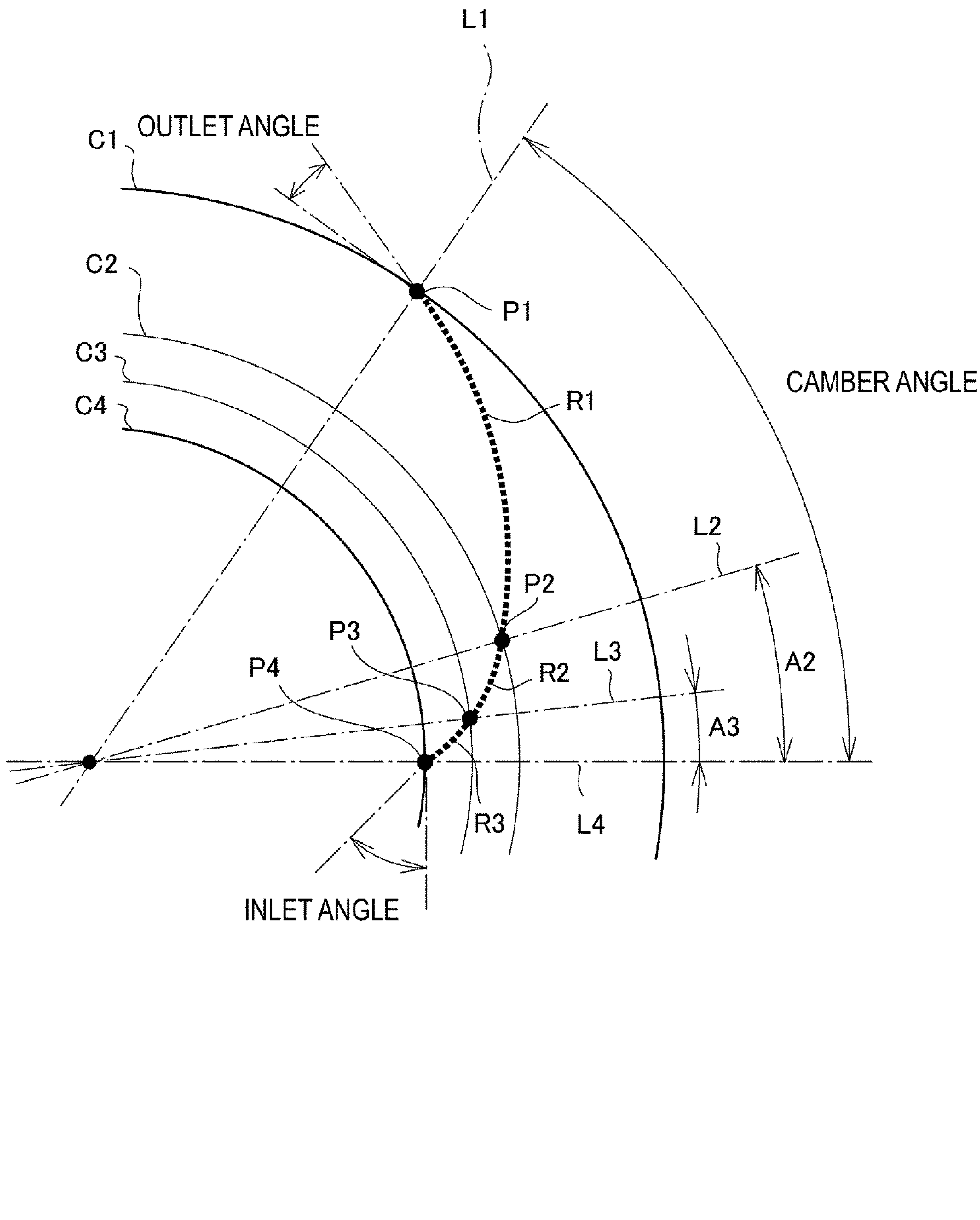

L1
C1
OUTLET ANGLE
C2
P1
C3
R1
C4
CAMBER ANGLE
L2
P2
P3
L3
A2
P4
R2
A3
R3
L4
INLET ANGLE

FIG.8

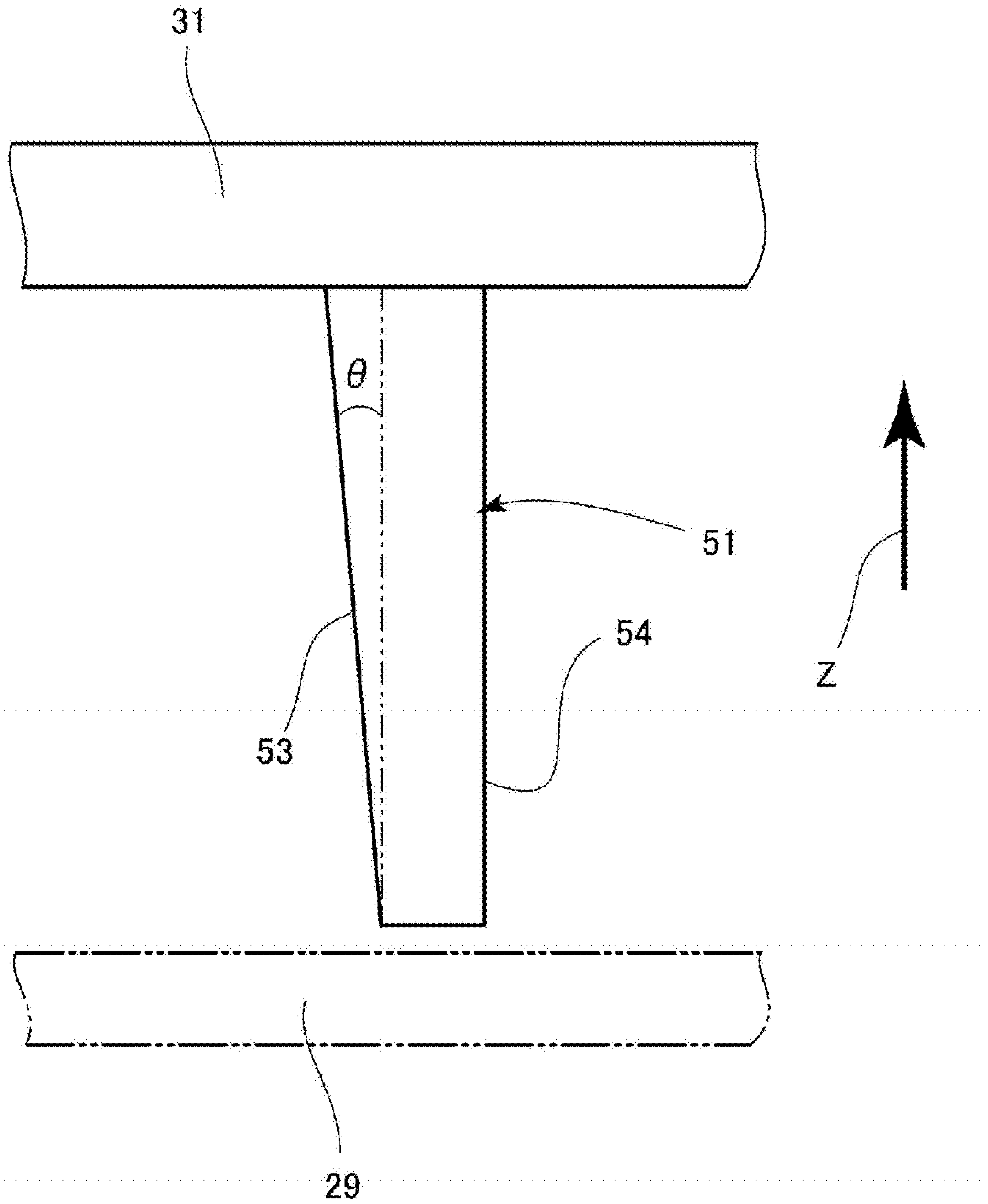


FIG.9

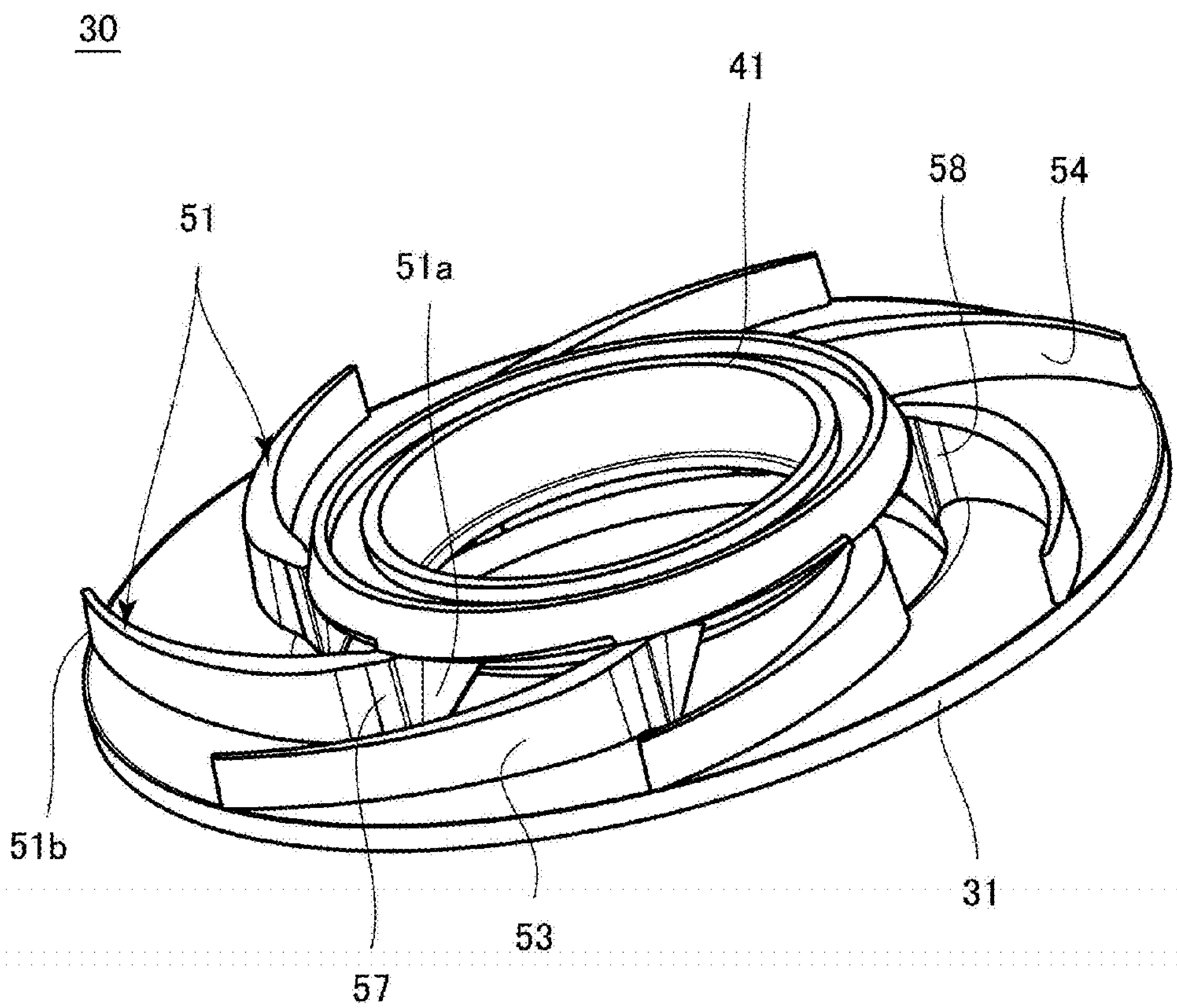


FIG.10

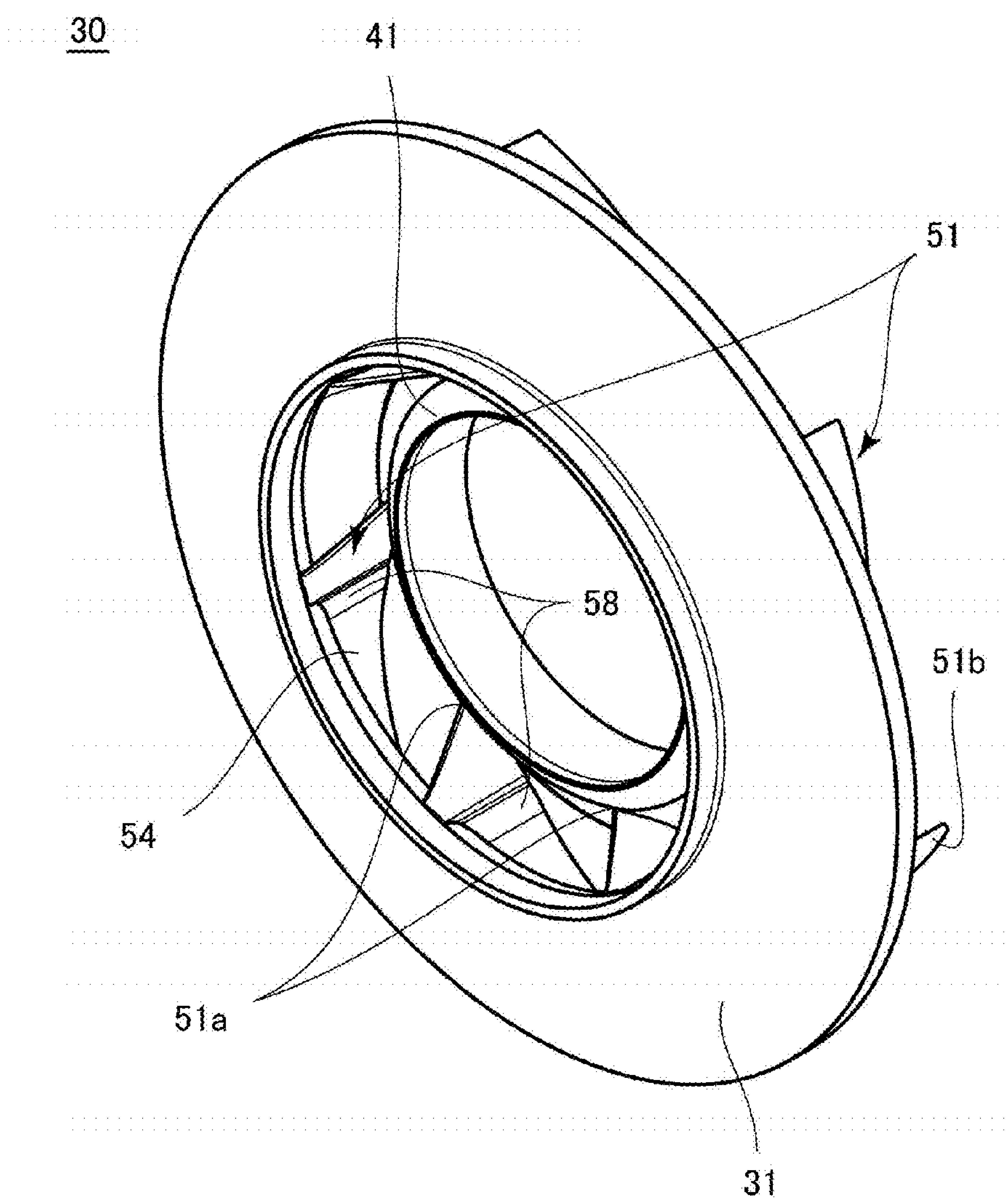


FIG.11

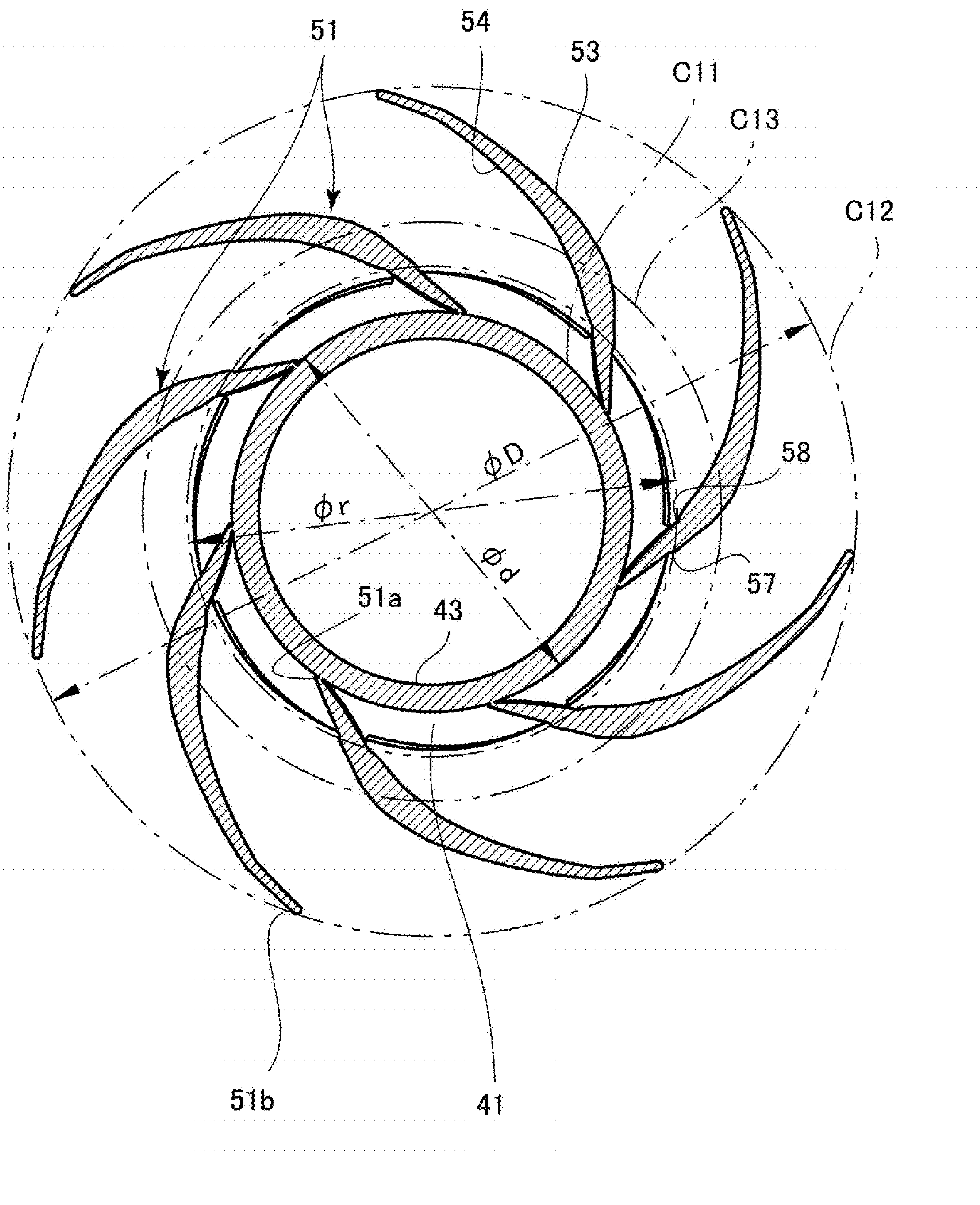


FIG.12

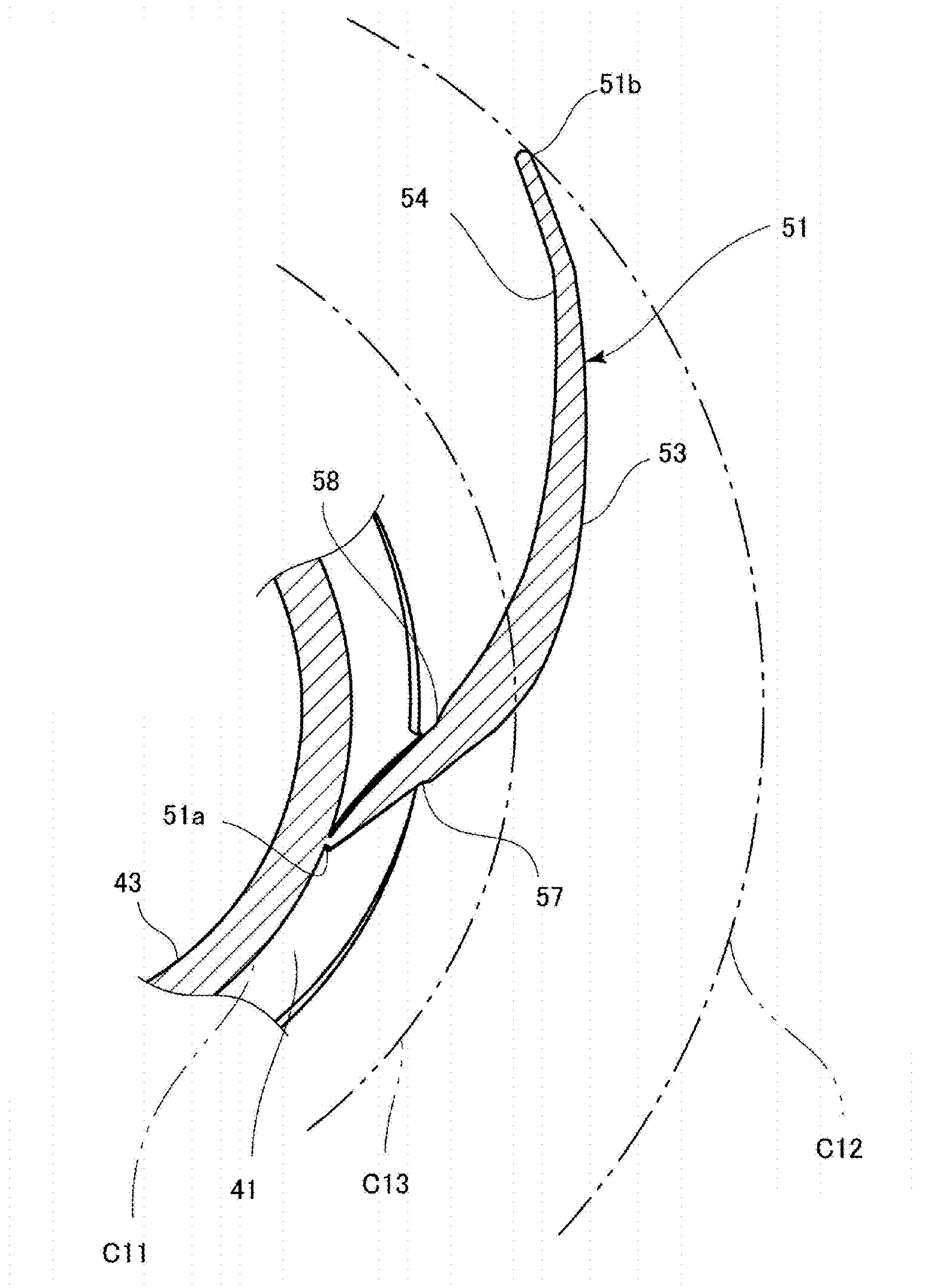


FIG.13

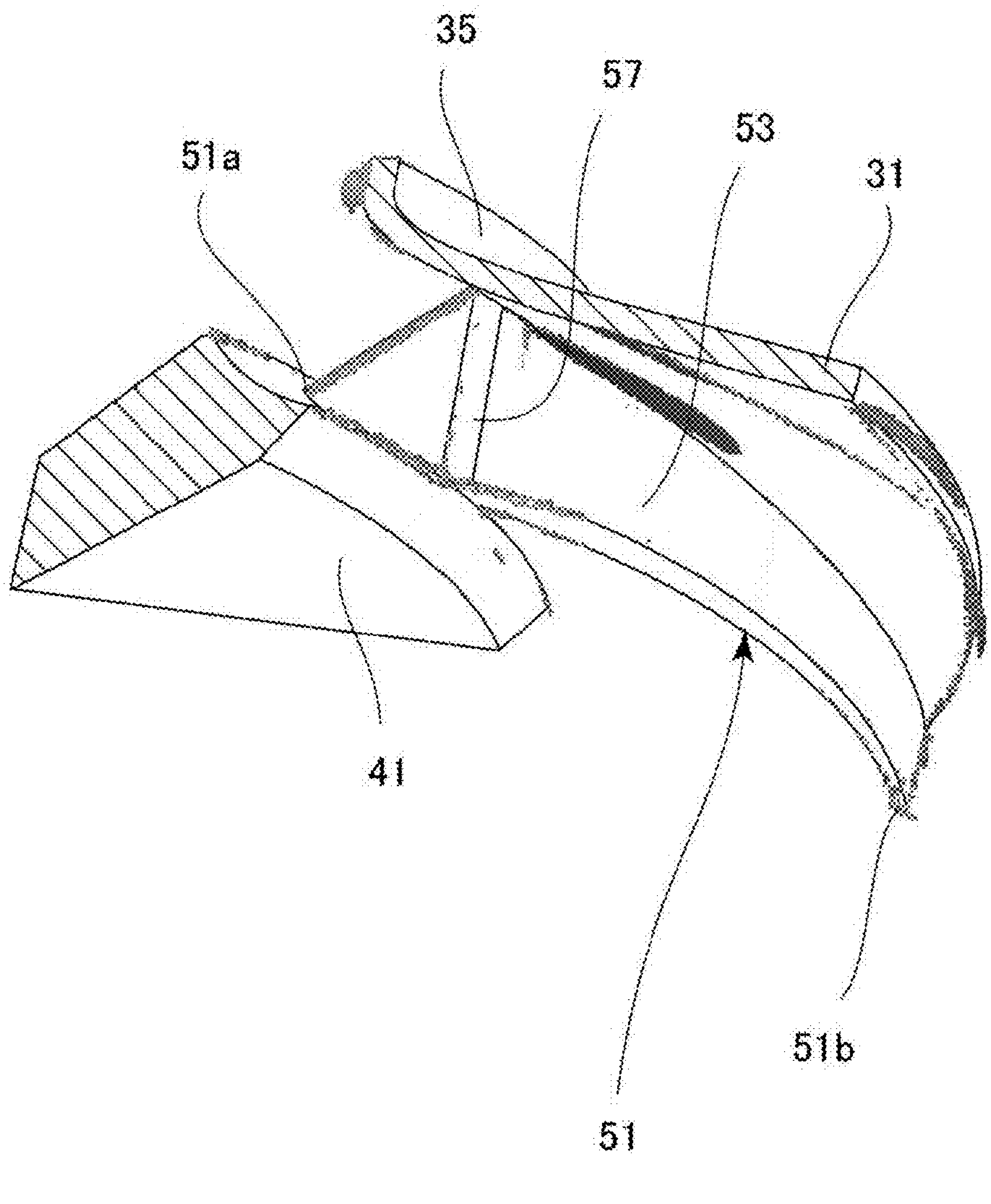


FIG.14

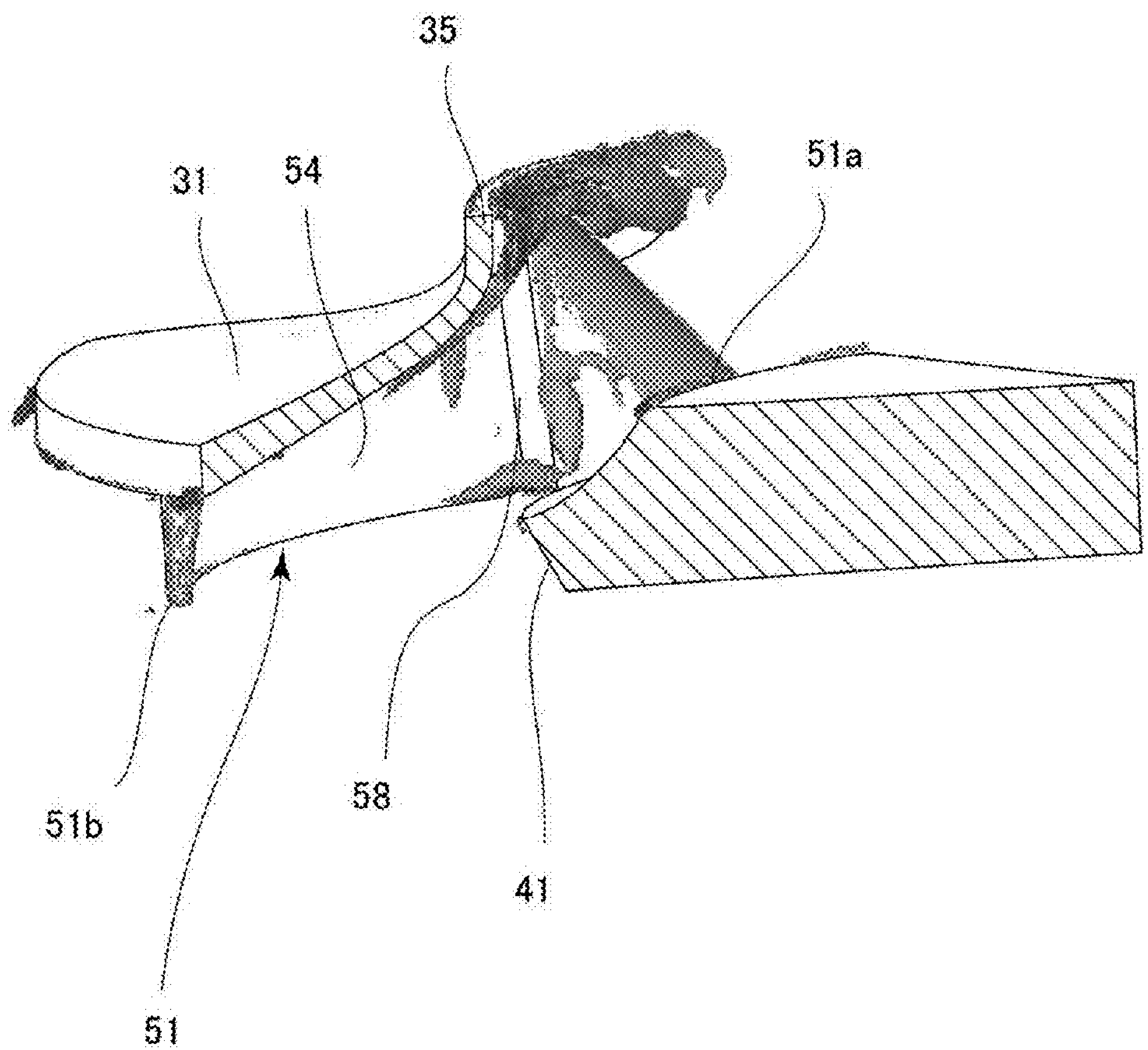


FIG.15

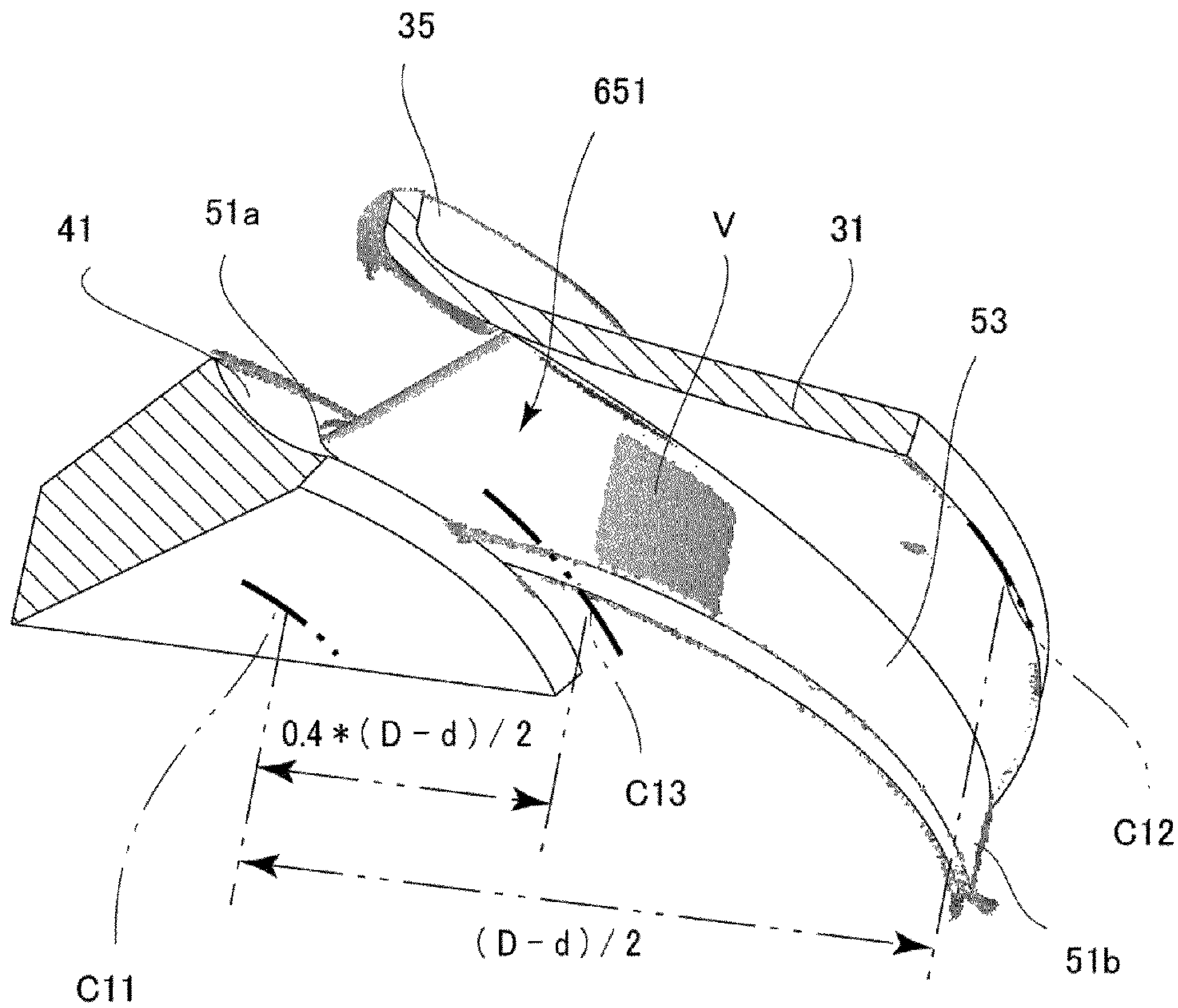


FIG.16

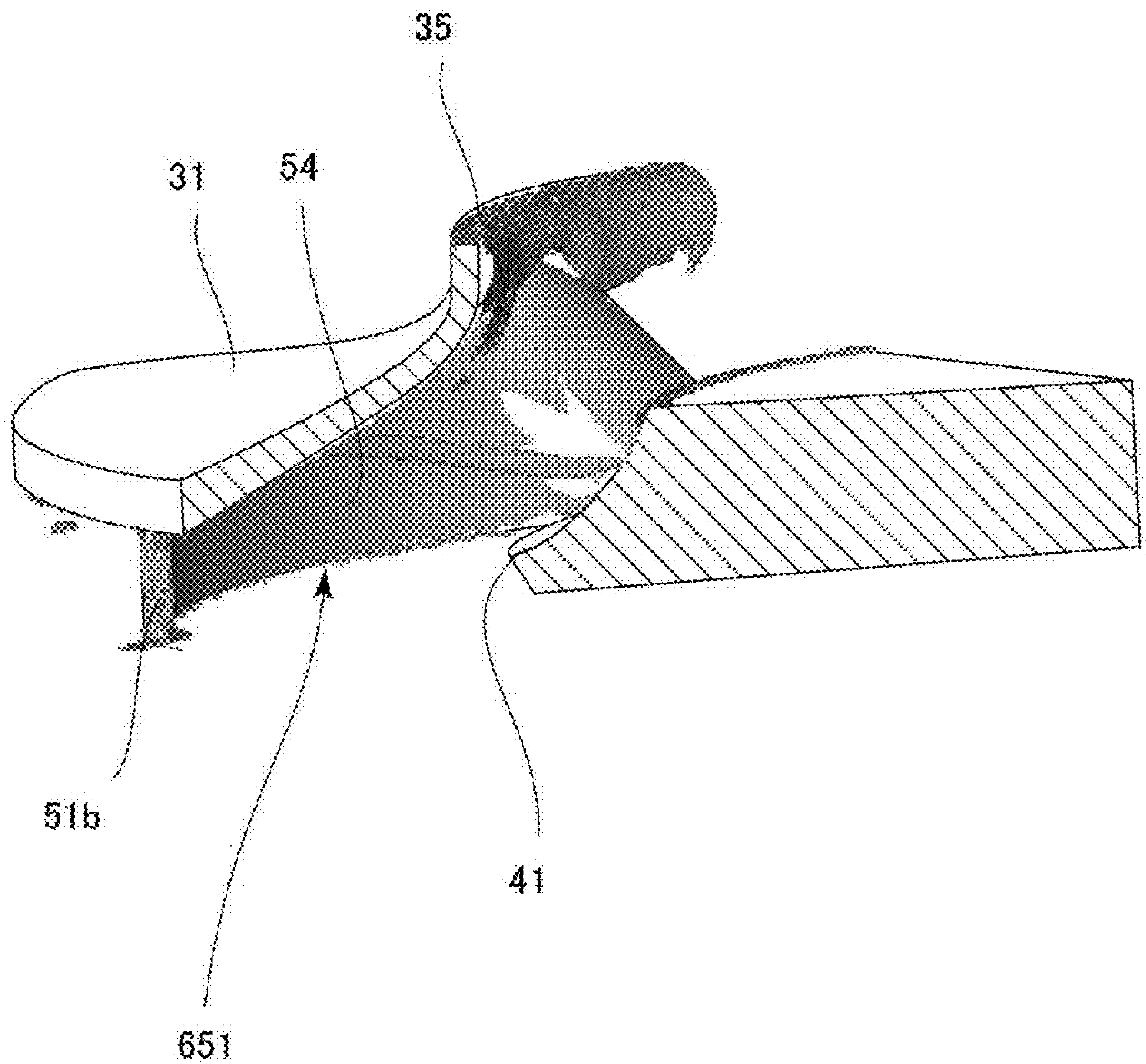


FIG.17

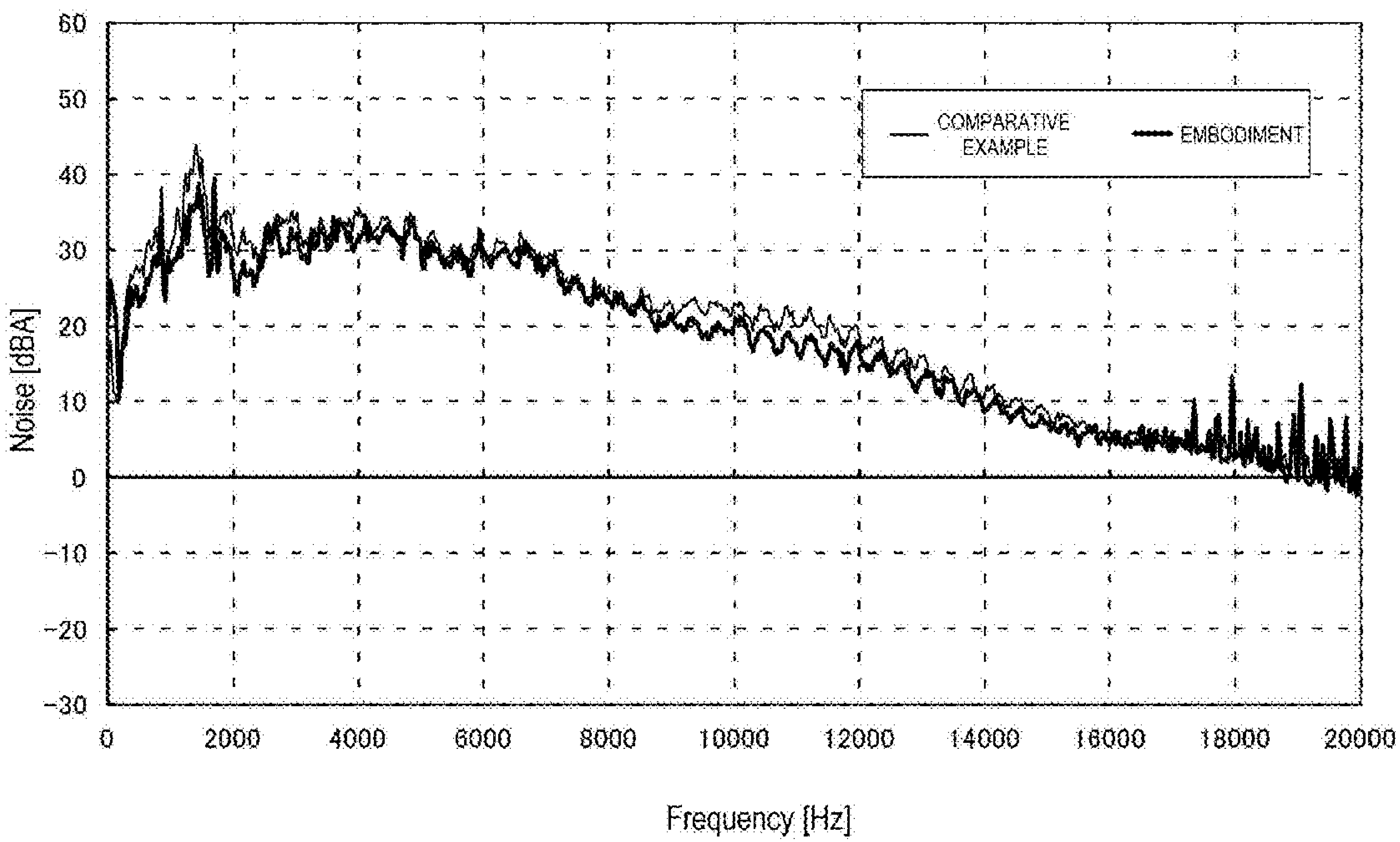
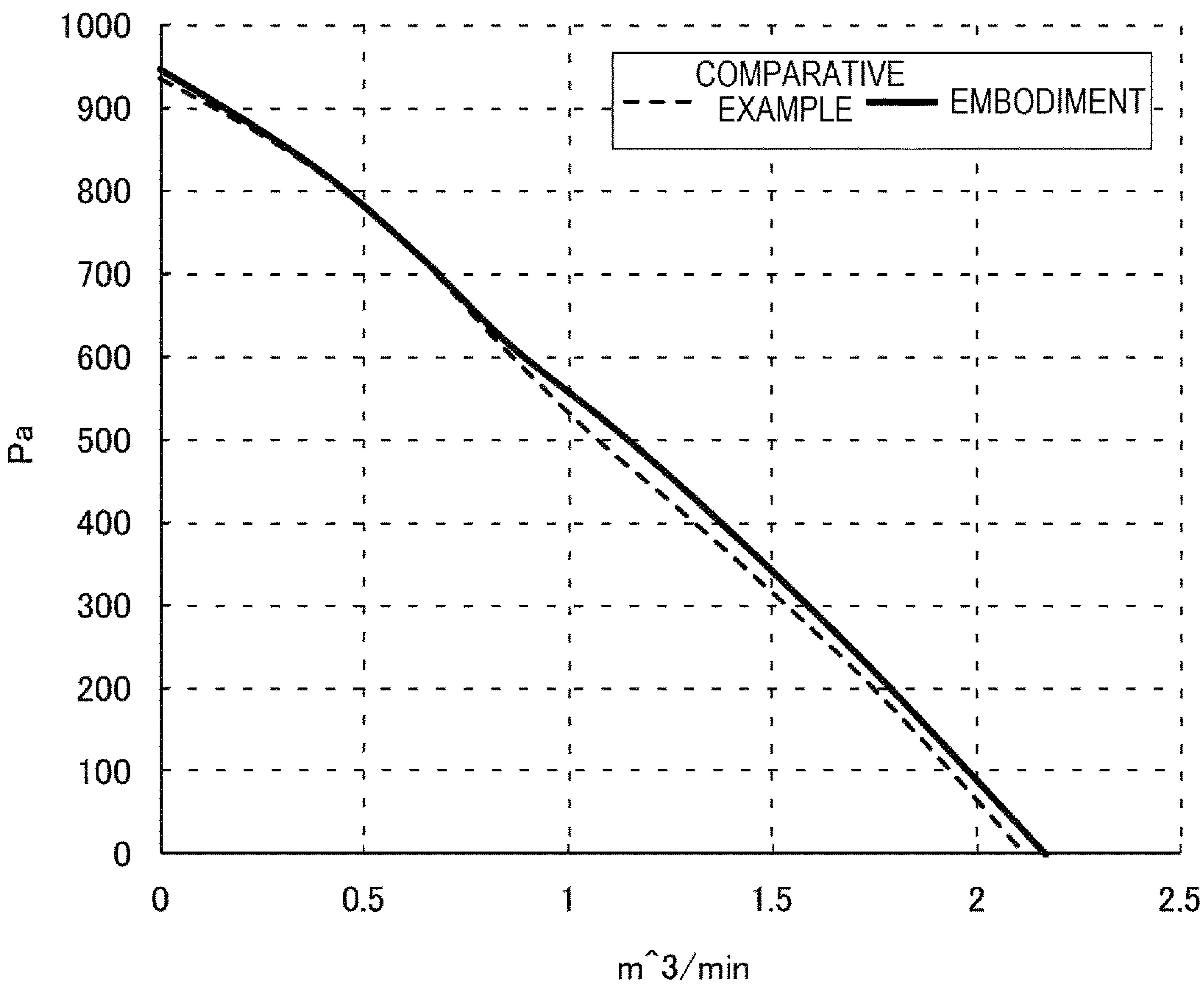

60
50
40
30
20
10
0
-10
-20
-30
Noise [dBA]
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
Frequency [Hz]
COMPARATIVE EXAMPLE
EMBODIMENT

FIG.18



1000
900
800
700
600
500
400
300
200
100
0
Pa
COMPARATIVE EXAMPLE
EMBODIMENT
0
0.5
1
1.5
2
2.5
m^3/min

FIG.19

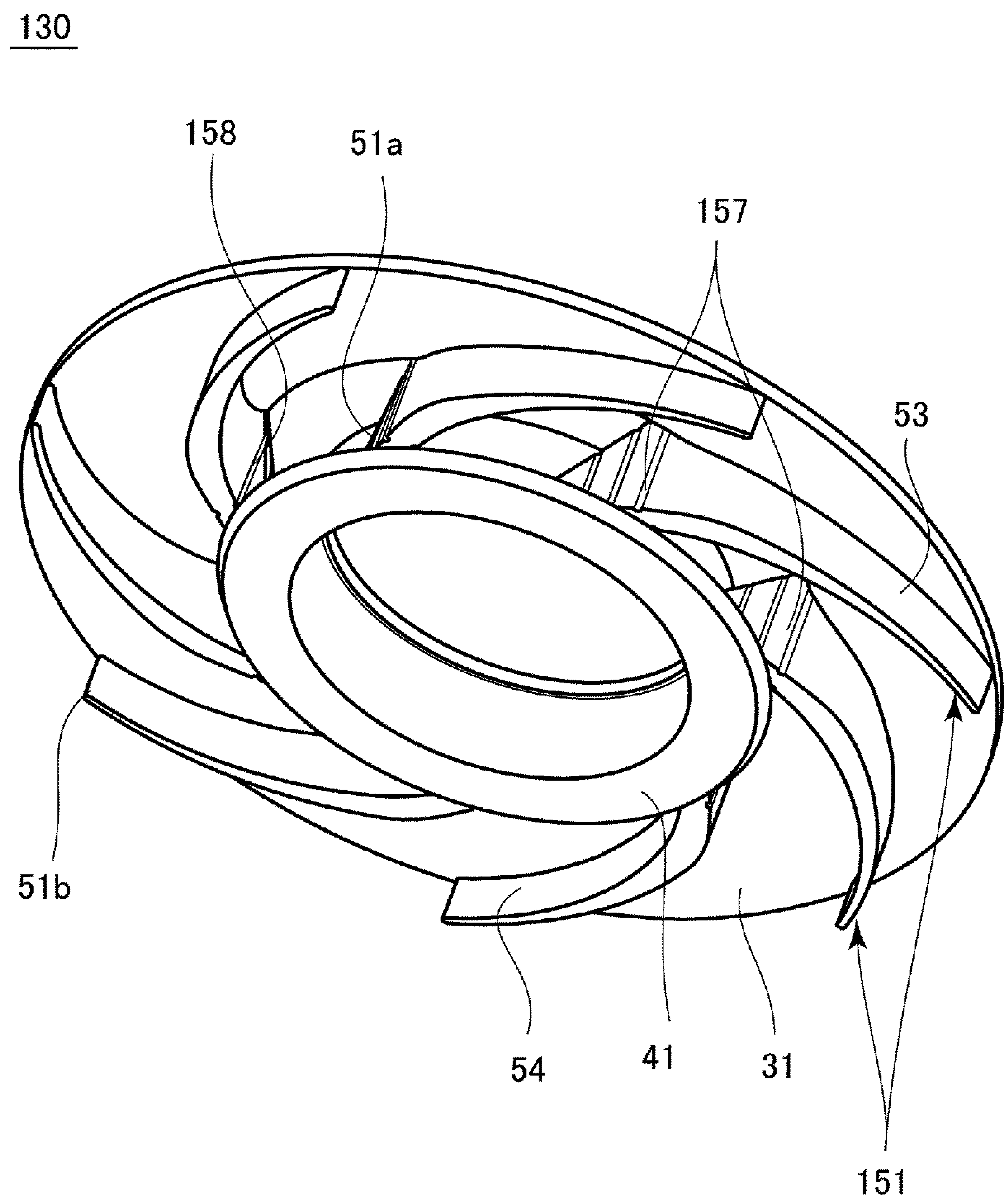


FIG.20

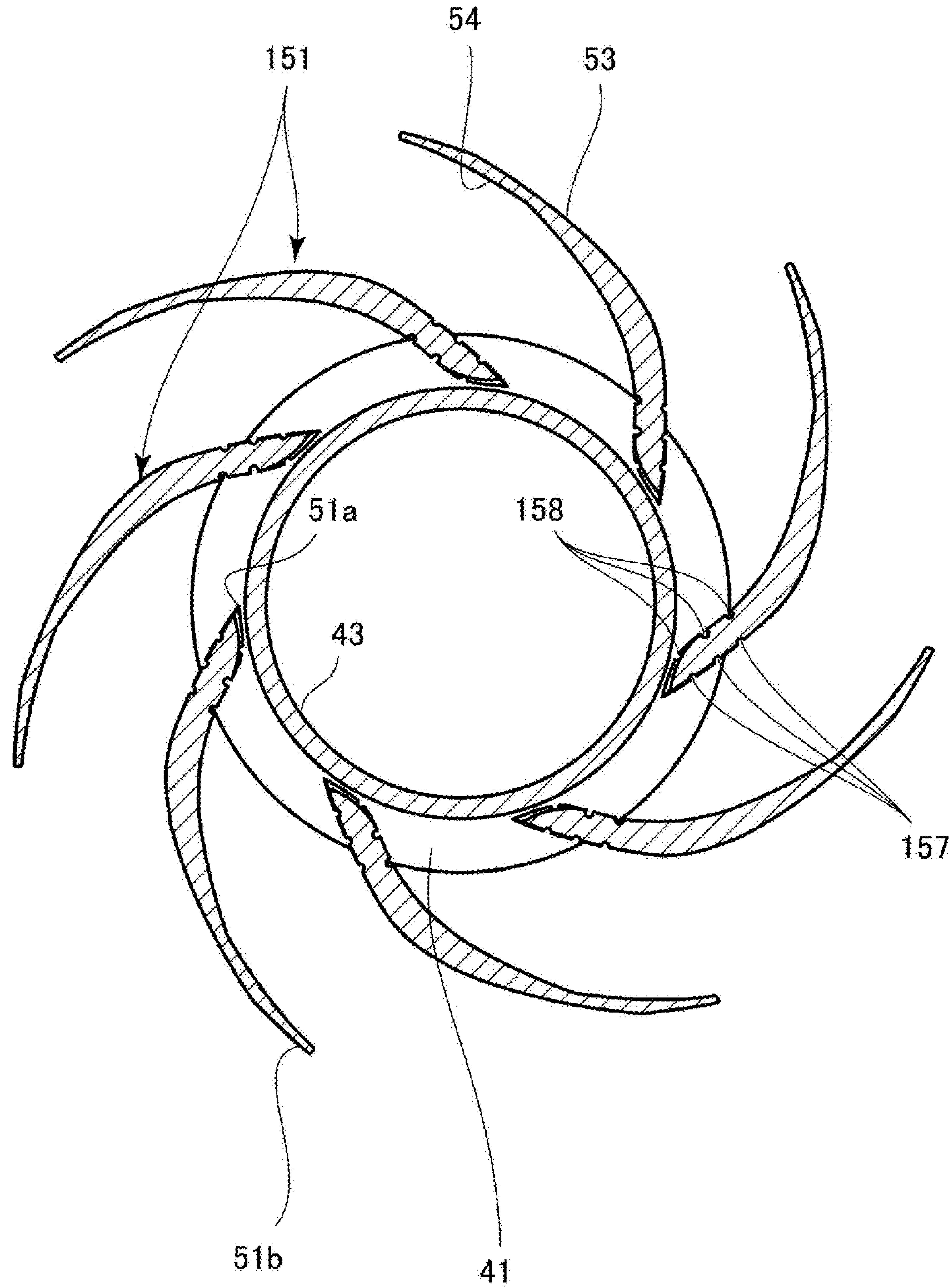


FIG.21

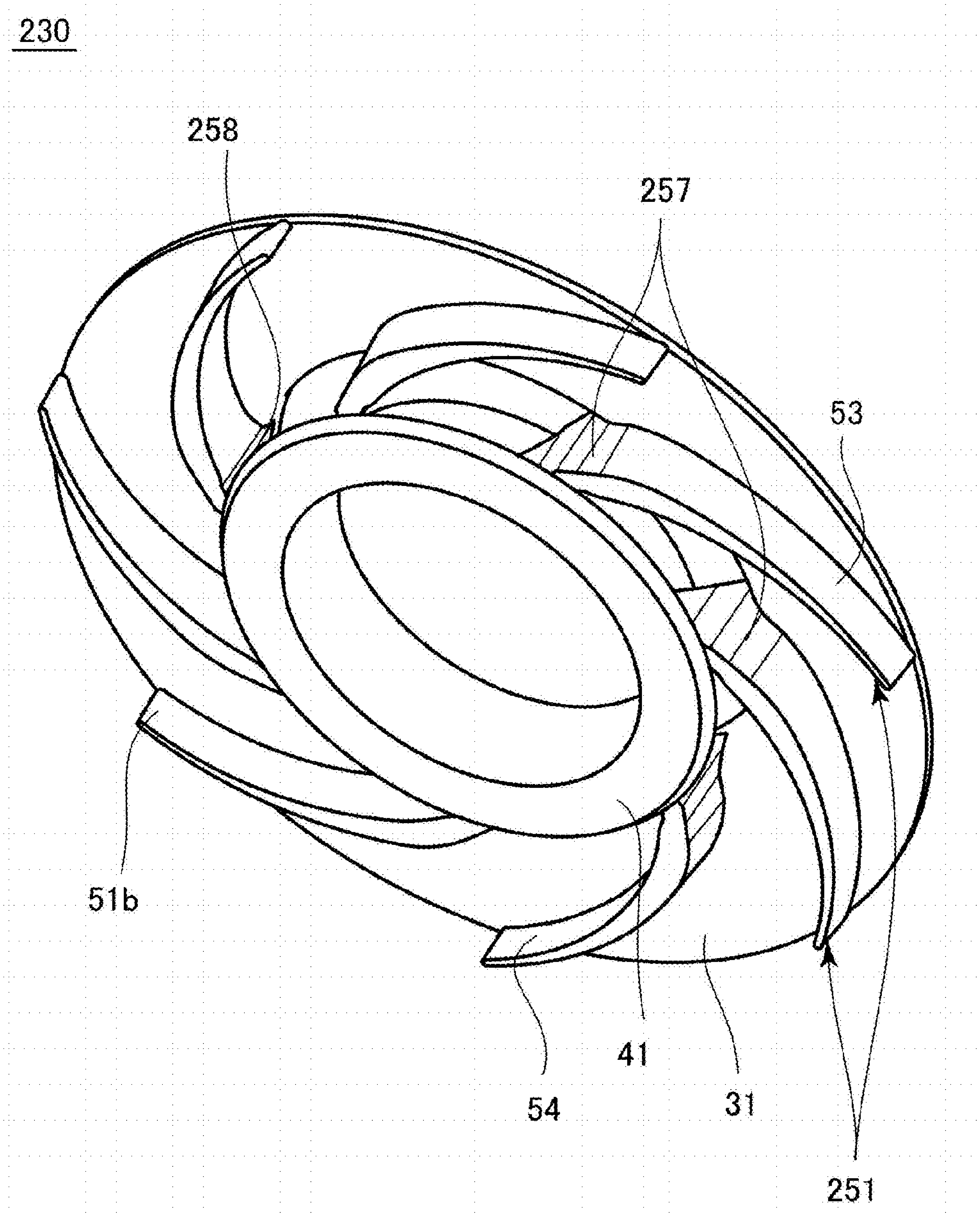


FIG.22

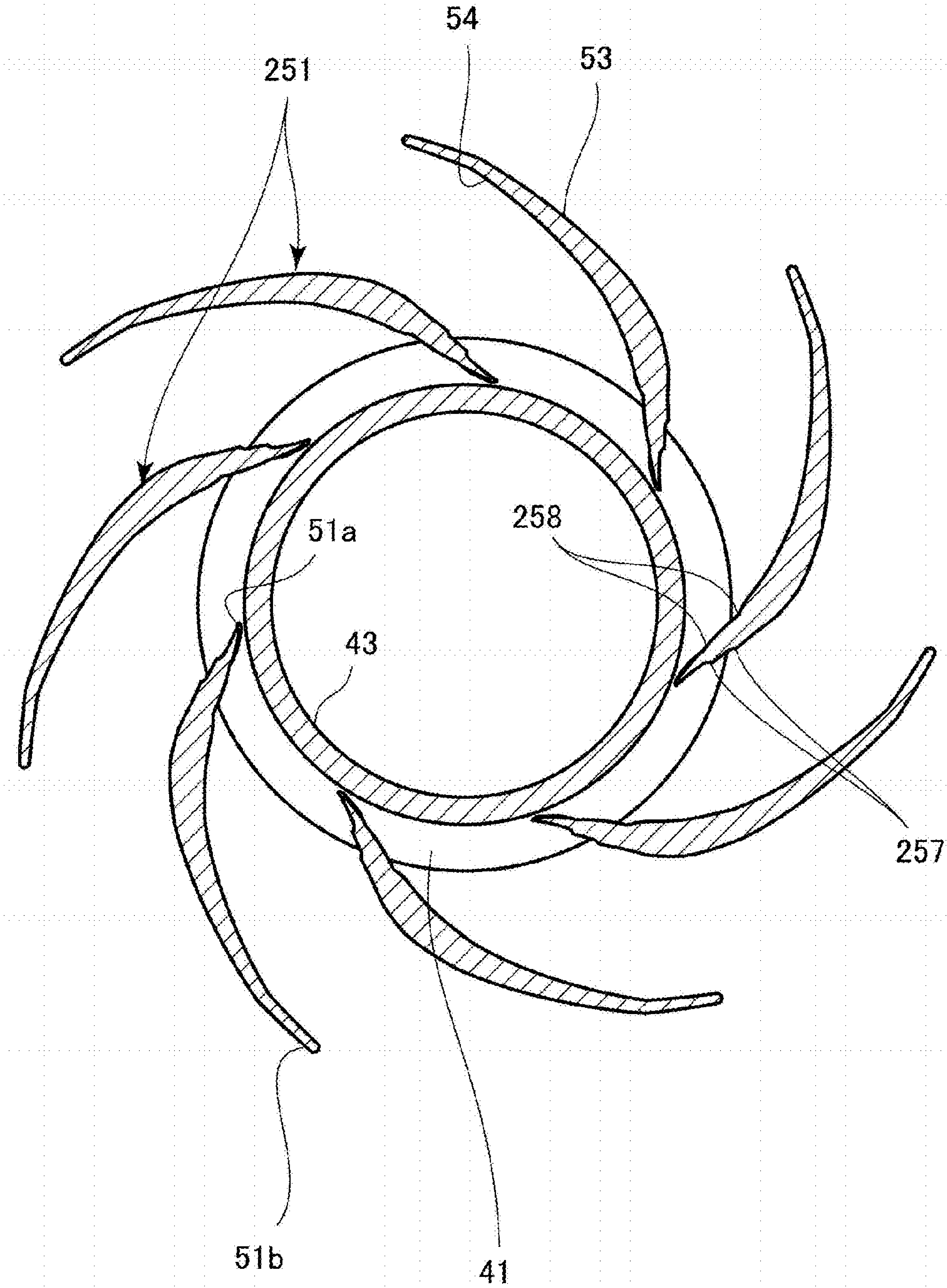


FIG.23

RELATED ART

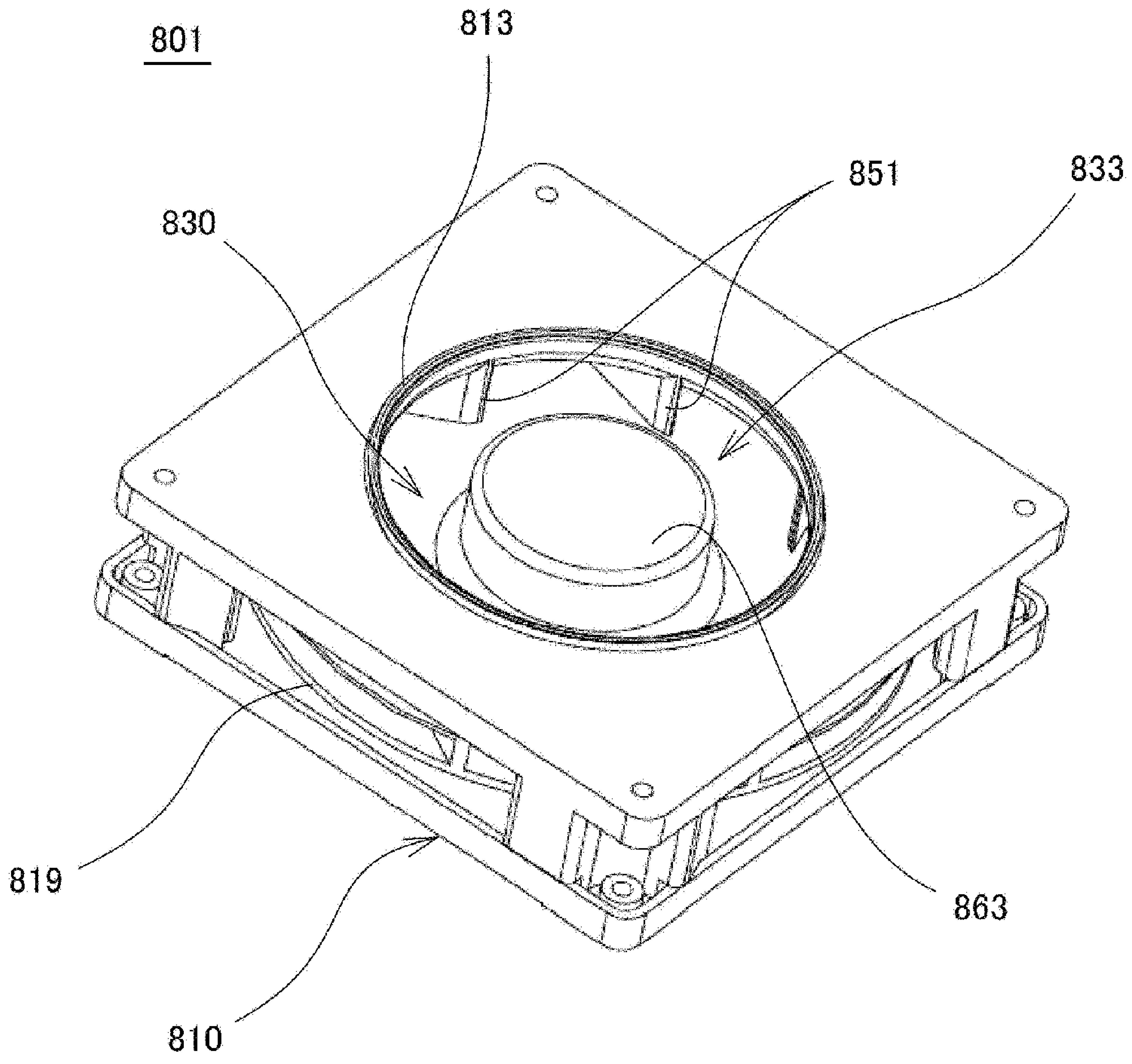
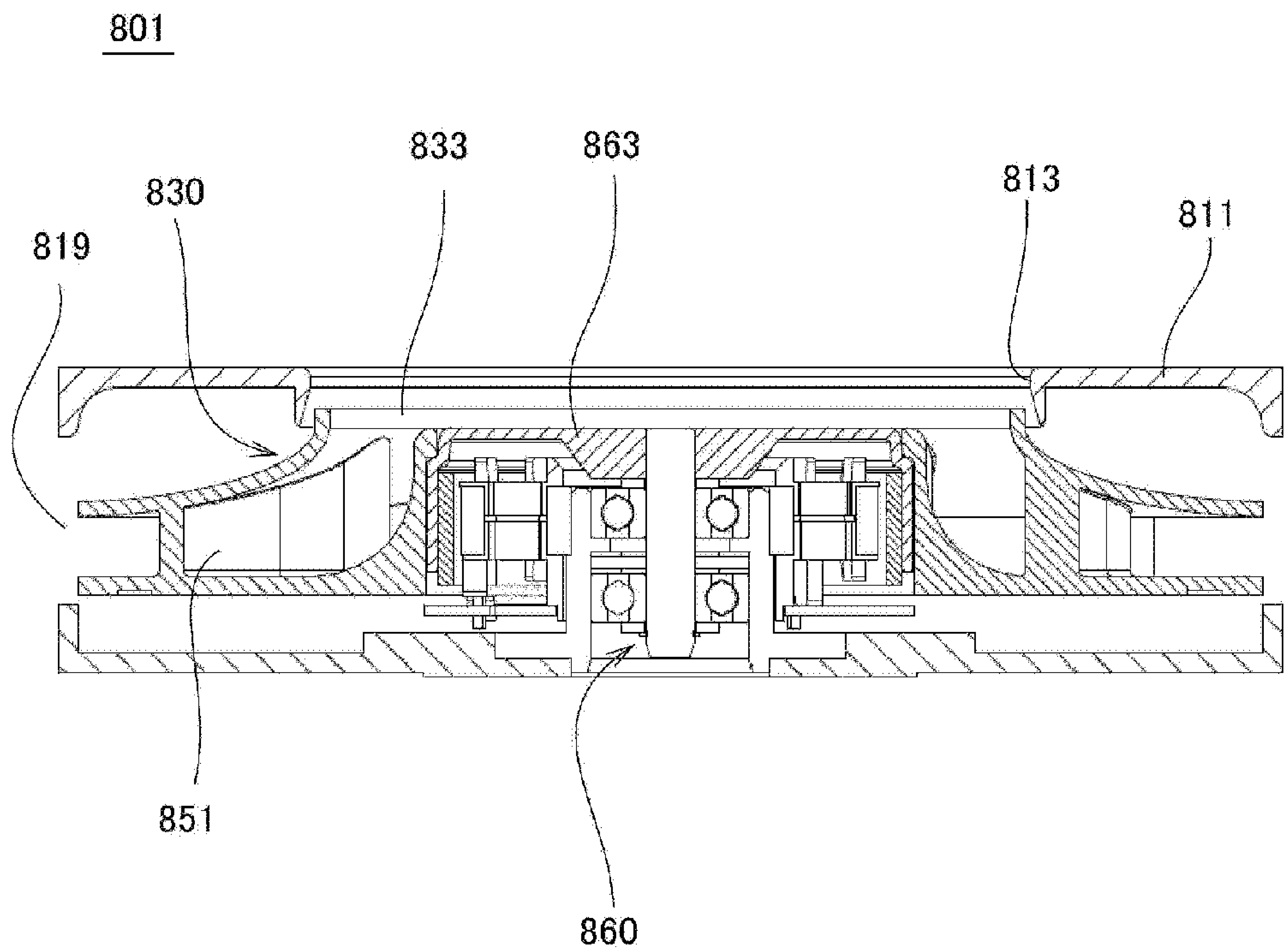


FIG.24

RELATED ART



CENTRIFUGAL FAN

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a centrifugal fan, and particularly, to a thin high-power centrifugal fan.

2. Description of the Related Art

FIG. **23** is a perspective view illustrating an example of a related-art centrifugal fan. FIG. **24** is a sectional side view illustrating the example of the related-art centrifugal fan.

As shown in FIGS. **23** and **24**, a centrifugal fan **801** is generally configured by installing an impeller **830** in a casing **810** having an inlet **813** (**833**) and an outlet **819**. The impeller **830** includes a plurality of blades **851** arranged around a rotating shaft of a motor **860**. The centrifugal fan **801** suctions air from the inlet **813** (**833**), makes the air flow through the blades (wings) from the center of the impeller **830**, and expels the air outward in the radial direction of the impeller **830** by a fluid force due to a centrifugal action according to rotation of the impeller **830**. The air expelled outward from the outer circumference of the impeller **830** is discharged from the outlet **819** of the casing **810**.

As shown in FIG. **24**, the centrifugal fan **801** is thin. The centrifugal fan **801** has the motor **860** provided at the substantially center portion of the casing **810** in order for rotating the impeller **830**. The motor **860** is an outer rotor type brushless motor disposed such that its rotor yoke **863** is fit in the impeller **830**.

This centrifugal fan **801** is widely used for cooling, ventilation, and air-conditioning of appliances, office automation equipment, and industrial equipment, blowers for vehicles, etc. The blowing performance and noise of the centrifugal fan **801** are greatly affected by the wing (blade) shape of the impeller **830** and the shape of the casing **810** (the structure of the centrifugal fan **801**).

Incidentally, in order to reduce noise or to improve blowing performance, it has been performed to optimize the shapes of impellers or the structures of casings, and various proposals have been made.

For example, JP-A-UM-H5-12692 discloses a turbo fan in which lengthwise recesses or circular recesses are formed on the pressure surface sides of blades, such that fan efficiency is improved.

JP-A-UM-S64-19100 discloses a multi-blade fan in which grooves are formed in the longitudinal directions of blades on the positive pressure surface sides of the blades, such that blade efficiency is improved.

JP-A-2006-9577 discloses a multi-blade fan in which stepped parts are formed such that the thickness of each blade decreases from the leading edge toward the trailing edge, whereby the noise of an impeller is reduced.

JP-A-UM-S63-160400 discloses a sirocco fan in which unevenness is formed on the upstream side of the pressure surface side of each blade, such that the operating efficiency of the main body of the fan is improved and noise is reduced.

With the progress of size reduction, thickness reduction, high-density mounting, and energy-saving of various apparatuses, it has been always required to improve the efficiency of a centrifugal fan to be mounted on those apparatuses.

At the same time, it has been always required to further reduce the level of noise generated by driving of a centrifugal fan.

SUMMARY OF THE INVENTION

The present invention has been made in view of the above circumstances, and an object of the present invention is to

provide a centrifugal fan which is thin and highly efficient and is capable of reducing generation of noise.

According to an illustrative embodiment of the present invention, there is provided a centrifugal fan including an impeller rotatable about a rotation axis, and a lower casing which is provided below the impeller. The impeller includes an upper shroud having an upper portion formed with an inlet, a lower shroud, and a plurality of blades arranged along a circumference direction between the upper shroud and the lower shroud. A fluid introduced from the inlet is discharged to a side of the impeller according to rotation of the impeller. The blades extend from an inner side area to an outer side area in a radial direction, and the blades are only connected to the lower shroud with the inner side area of the blades such that at least an outer circumferential side portion of each blade faces an upper surface of the lower casing. A surface of the lower casing, which faces the impeller, configures a portion of a wall surface which guides the fluid introduced from the inlet. A surface of each blade at a side of a leading edge portion is formed with a discontinuous portion having a step shape.

In the above centrifugal fan, the discontinuous portion may be formed on at least one of a pressure surface and a negative pressure surface of each blade.

In the above centrifugal fan, the step shape of the discontinuous portion may be formed along a direction substantially parallel to the rotation axis.

In the above centrifugal fan, the discontinuous portion may include at least one of one or more step shapes and one or more groove shapes.

In the above centrifugal fan, the discontinuous portion may be formed within a range extending in a radial direction perpendicular to the rotation axis between the leading edge portion and a predetermined distance outward of the leading edge portion in the radial direction, and the predetermined distance may be 40% of a distance from the leading edge portion to a trailing edge portion of each blade in the radial direction.

In the centrifugal fan, each blade may have a shape which becomes thinner as increasing a distance from the upper shroud in a direction parallel to the rotation axis of the impeller.

In the above centrifugal fan, each blade may have a tapered shape such that a pressure surface thereof approaches a negative pressure surface thereof as increasing distance from the upper shroud in a direction parallel to the rotation axis of the impeller.

In the above centrifugal fan, as seen from a direction in which the rotation axis of the impeller extends, a pressure surface of each blade may have a shape in which at least three arcs are connected, or a shape expressed by a combination of a plurality of high-dimensional functions passing three points.

The above centrifugal fan may further include a motor which is attached to the lower shroud and configured to rotate the impeller to introduce the fluid from the inlet and discharge the fluid to the side of the impeller.

According to the above configuration, in the surface at the side of the leading edge portion of each blade, the discontinuous portion is formed in a step shape. Therefore, a centrifugal fan which is thin and highly efficient and is capable of reducing generation of noise can be provided.

BRIEF DESCRIPTION OF THE DRAWINGS

In the accompanying drawings:

FIG. **1** is a plan view illustrating a centrifugal fan according to an illustrative embodiment of the present invention;

FIG. **2** is a cross-sectional view taken along the line A-A of FIG. **1**;

FIG. **3** is a partial enlarged view of FIG. **2**;

FIG. **4** is a side vide of an impeller;

FIG. **5** is a bottom view of the impeller;

FIG. **6** is a cross-sectional view taken along the line B-B of FIG. **5**;

FIG. **7** is a view illustrating a shape of a pressure surface of a blade;

FIG. **8** is a view schematically illustrating a cross section of the blade;

FIG. **9** is a perspective view illustrating a bottom side of the impeller;

FIG. **10** is a perspective view illustrating a top side of the impeller;

FIG. **11** is a cross-sectional view taken along the line G-G of FIG. **4**;

FIG. **12** is an enlarged view of a portion of FIG. **11**;

FIG. **13** is a view illustrating a vortex generation area on a pressure surface side during rotation of the impeller;

FIG. **14** is a view illustrating a vortex generation area on a negative pressure surface side during rotation of the impeller;

FIG. **15** is a view illustrating a vortex generation area on a pressure surface side in an impeller without step portions;

FIG. **16** is a view illustrating a vortex generation area on a negative pressure surface side in the impeller without step portions;

FIG. **17** is a graph illustrating a noise level of centrifugal fans;

FIG. **18** is a diagram illustrating a P-Q curve of the centrifugal fans;

FIG. **19** is a perspective view illustrating an impeller of a centrifugal fan according to a first modification of the illustrative embodiment;

FIG. **20** is a view illustrating a blade shape of the impeller of the centrifugal fan according to the first modification;

FIG. **21** is a perspective view illustrating an impeller of a centrifugal fan according to a second modification of the illustrative embodiment;

FIG. **22** is a view illustrating a blade shape of the impeller of the centrifugal fan according to the second modification;

FIG. **23** is a perspective view illustrating an example of a related-art centrifugal fan; and

FIG. **24** is a sectional side view illustrating the example of the related-art centrifugal fan.

DETAILED DESCRIPTION

Hereinafter, a centrifugal fan according to an illustrative embodiment of the present invention will be described.

[Description of Overall Structure of Centrifugal Fan]

FIG. **1** is a plan view illustrating a centrifugal fan according to an illustrative embodiment of the present invention. FIG. **2** is a cross-sectional view taken along the line A-A of FIG. **1**. FIG. **3** is a partial enlarged view of FIG. **2**.

Referring to FIGS. **1** to **3**, a centrifugal fan **1** includes a casing **10**, an impeller **30**, and a motor **60**. Except for a portion where the motor **60** is fit, the centrifugal fan **1** is generally configured in a cuboid shape which is substantially square as seen in a plan view. The centrifugal fan **1** is a thin fan whose dimension in a vertical direction (height) is comparatively small. The impeller **30** is mounted on a rotor **63** which rotates together with a shaft **61** of the motor **60**. The centrifugal fan **1** rotates the impeller **30** by the motor **60**. The centrifugal fan **1** discharges an air (an example of a fluid) introduced from an inlet **33** to the side of the impeller **30** by rotation of the impeller **30**. That is, the air introduced from the inlet **33** passes through blades **51** of the impeller **30** and is expelled outward in the radial direction of the impeller **30** by a fluid force due to a centrifugal action according to the rotation of the impeller **30**. The air is discharged from outlets **19** of the casing **10** which are at the side of the impeller **30**.

The motor **60** is, for example, an outer rotor type brushless motor. The motor **60** is mounted at the center portion of a lower casing **21** by fastening members such as screws, bolts, and the like. The motor **60** has the rotor **63** which has a cup shape, and the rotor **63** is open toward a lower side. On the inner surface of a side peripheral portion of the rotor **63**, an annular magnet **65** is mounted. The shaft **61** is fit into the center portion of the rotor **63**.

The shaft **61** is rotatably supported by a pair of bearings **66***a* disposed in a bearing holder **66**. On an outer circumferential portion of the bearing holder **66**, a stator **67** is mounted. The stator **67** includes stacked stator cores, an insulator formed by winding a coil and mounted on the state cores, and so on. The stator **67** is disposed to face the magnet **65** with a predetermined gap in a radial direction (in a left-right direction in FIG. **2**). The stator **67** is connected to a circuit board **69**. The circuit board **69** is, for example, a printed circuit board. On the circuit board **69**, various components such as an electronic component for controlling the motor **60** is mounted, and a drive circuit for the motor **60** is mounted.

The casing **10** is configured by assembling an upper casing **11** and a lower casing **21**. Specifically, the upper casing **11** and the lower casing **21** are assembled with each other by fastening screws **14** which are positioned at four corners as seen in a plan view, whereby the casing **10** is configured. The screws **14** are, for example, bolts which are fit from a side of the lower casing **21**. The upper casing **11** and the lower casing **21** are assembled with each other, for example, with supports interposed therebetween at the portions where the screws **14** are arranged. In this case, the supports may be configured integrally with either one of the upper casing **11** and the lower casing **21**. The outlets **19** may be formed between the upper casing **11** and the lower casing **21**, for example, at side portions of the casing **10** except for the fastening portions of the upper casing **11** and the lower casing **21** using the screws **14**.

The impeller **30** is disposed to be accommodated in the casing **10**. Above the impeller **30**, the upper casing **11** is disposed, and below the impeller **30**, the lower casing **21** is disposed. That is, the centrifugal fan **1** is configured by holding the impeller **30** between the upper casing **11** and the lower casing **21**.

The impeller **30** includes an upper shroud **31**, a lower shroud **41**, and a plurality of blades **51** disposed between the upper shroud **31** and the lower shroud **41**. At the center portion of the impeller **30**, the inlet **33** is formed to be open toward the upper side. The inlet **33** is formed to be surrounded by an upper end portion **35** of the upper shroud **31** on the inner side. The plurality of blades **51** are arranged at appropriate intervals on a circumference direction.

The individual blades **51** have the same curved shape. That is, each blade **51** has a shape inclined backward with respect to a rotation direction. In FIGS. **1** to **3**, the shapes of the blades **51** are simply shown. The specific shapes of the blades **51** will be described below. The upper shroud **31**, the lower shroud **41**, and the blades **51** may be formed by integral molding using, for example, synthetic resins.

At the center portion of the impeller **30**, there is disposed the lower shroud **41** into which the rotor **63** is fit. At the center portion of the lower shroud **41**, a cylindrical portion **43** is formed to allow the rotor **63** to be disposed therein.

The rotor **63** is fit into the cylindrical portion **43** formed at the center portion of the lower shroud **41**, thereby holding the impeller **30**. The rotor **63** is disposed inside the inlet **33** to protrude upward toward the outside of the inlet **33**. Also, in order to prevent air which is suctioned from the inlet **33** from being blocked by the rotor **63** while making the centrifugal fan **1** comparatively thin, the vertical height of the portion of the rotor **63** holding the cylindrical portion **43** is set to be comparatively low.

The upper casing **11** is made of, for example, a resin such as engineering plastic. At the center portion of the upper casing **11**, an opening **13** is formed. The opening **13** is circular as seen in a plan view. The opening **13** is formed such that air is introduced into the inlet **33** of the impeller **30**. The opening **13** has an inside diameter slightly larger than that of the inlet **33** formed in the upper shroud **31**. That is, in the present illustrative embodiment, the size of the opening **13** is substantially the same as the size of the inlet **33**.

The lower casing **21** is made of, for example, a plate of a metal such as iron. At the center portion of the lower casing **21**, a recess **23** is formed downward. The recess **23** is formed in a bowl shape. As shown in FIG. **2**, in the present illustrative embodiment, in the recess **23**, the motor **60**, and the drive circuit for the motor **60** such as the circuit board **69** are installed. The motor **60** is mounted on the lower casing **21** by fastening members such as screws and bolts; however, the motor **60** may be mounted on the lower casing **21** by fixing the lower portion of the bearing holder **66** into the recess **23**, instead of using the fastening members.

The outer circumferential portion of the lower casing **21** has a side plate bent in an axial direction (in an upper-lower direction of FIG. **2**). The rigidity of the lower casing **21** can be improved by providing the side plate.

In the upper surface of the lower casing **21**, a portion around the recess **23** is a partition portion **29** facing the lower surface of the impeller **30**. The partition portion **29** is formed in a flat plate shape to be close to the lower surface of the impeller **30**.

As shown in FIG. **2**, the lower shroud **41** of the impeller **30** is provided only on a portion of the blades **51** at a side of the shaft (the rotation axis of the impeller **30**) **61** such that at least an outer circumferential side portion of each blade **51** faces the partition portion **29**. That is, the blades **51** are exposed at a portion of the impeller **30** facing the partition portion **29**. A surface of the lower casing **21**, which faces the impeller **30**, configures a portion of a wall surface which guides air introduced from the inlet **33** to the side. The blades **51** are disposed to face the partition portion **29** with a predetermined gap in an axial direction. Incidentally, the lower portion of each blade **51** may be partially or wholly exposed to the partition portion **29**.

As shown in FIG. **3**, a portion of the upper surface of the lower shroud **41** has a curved surface **49** which forms a curved line having an arc shape convex downward in a lateral cross section. An outer circumferential end portion **45** of the lower shroud **41** is positioned in the vicinity of the vertically lower side of an upper end portion **35** of the upper shroud **31**. Also, an inner circumferential end portion **47** of the lower shroud **41** is positioned in the vicinity of an upper end portion **63***a* of the outer periphery of the rotor **63**. The curved surface **49** is formed between the outer circumferential end portion **45** and the inner circumferential end portion **47**. The lowermost portion of the curved surface **49** is the outer circumferential end portion **45**.

The dimension of the outside diameter of the impeller **30** which is accommodated in the casing **10** is set to be smaller than the dimension of one side of the casing **10**. Therefore, the impeller **30** does not protrude from the outer edge of the casing **10** when rotating, and thus contact of the impeller **30** with other members, damages due to contact, and the like can be reduced or prevented.

The lower casing **21** serves not only as a main plate for guiding air in the impeller **30**, but also the substrate of the casing **10**. For this reason, setting of the gap which is formed between the impeller **30** and the partition portion **29** may be important. In a case where the gap is excessively large, air suctioned from the inlet **33** flows even into the gap while passing through the blades **51**. As a result, the pressure of air expelled from the impeller is reduced, and thus a blowing characteristic is reduced. Meanwhile, in a case where the gap is excessively small, there is the following problem. That is, if a variation occurs in the accuracy of the dimensions of each component, there is a possibility that the blades **51** will come into contact with the partition portion **29**. In order to prevent this contact, it is necessary to manage the accuracy of the dimensions of each component with a high degree of accuracy, and thus the manufacturing cost of the centrifugal fan **1** increases. In view of those problems, the gap between the impeller **30** and the partition portion **29** is appropriately set.

[Description of Structure of Impeller **30**]

Subsequently, the structure of the impeller **30** will be described in more detail.

FIG. **4** is a side vide of the impeller **30**. FIG. **5** is a bottom view of the impeller **30**. FIG. **6** is a cross-sectional view taken along the line B-B of FIG. **5**.

Referring to FIGS. **4** to **6**, the impeller **30** is a thin impeller which is roughly a disk shape. Therefore, the centrifugal fan **1** can be configured to be thin. As shown in FIG. **5**, in the impeller **30**, for example, seven blades **51** are arranged. Each blade **51** has a pressure surface **53** and a negative pressure surface **54**. The pressure surface **53** is directed to a leading side of the impeller **30** in the rotation direction (a counter-clockwise direction, that is, a direction shown by an arrow R in FIG. **5**). The negative pressure surface **54** is directed to the opposite side to the pressure surface **53**.

The blades **51** are backward inclined blades, and are of a so-called turbo type. The blades **51** have a blade shape inclined backward with respect to the rotation direction. The specific shape of each blade **51** is, for example, as follows. That is, as shown in FIG. **7** to be described below, as the pressure surface **53** is seen from a direction in which the rotation axis of the impeller **30** extends, the pressure surface **53** has roughly a shape in which three arcs are connected. These arcs are connected such that neighboring arcs are tangent to each other.

An edge of each blade **51** on the rotation axis side of the impeller **30**, that is, a side of the inlet **33** becomes a leading edge, and an edge of each blade **51** on the side peripheral surface side of the impeller **30** becomes a trailing edge. As shown in FIG. **6**, the leading edge of each blade **51** is configured in a tapered shape such that the leading edge becomes closer to the rotation axis of the impeller **30** as it approaches the lower shroud **41** from the upper shroud **31**. The leading edge of each blade **51** and the lower shroud **41** are connected at a leading edge portion **51***a*. The trailing edge of each blade **51** has a shape substantially perpendicular to the rotation axis of the impeller **30** (a trailing edge portion **51***b*).

FIG. **7** is a view illustrating the shape of the pressure surface **53** of the blade **51**.

In the present illustrative embodiment, the inlet angle, outlet angle, and camber angle of each blade **51** are set to about 45°, about 30°, and about 55°, respectively. However, the inlet angle, outlet angle, and camber angle of each blade **51** are not limited to those values. Herein, the term "inlet angle" refers to an angle which is formed by a tangent line of an inner circumferential edge (a circle having the rotation axis of the impeller **30** as its center and having a circumference on which the leading edge of the blade **51** as seen in a bottom view) and a tangent line of a curved line indicating the pressure surface **53** and shown in FIG. **7** at a point where the inner circumferential edge and the curved line indicating the pressure surface **53** are in contact with each other, and is 90° or less. The term "outlet angle" refers to an angle which is formed by a tangent line of an outer circumferential edge (a circle having the rotation axis of the impeller **30** as its center and having a circumference on which the trailing edge of the blade **51** as seen in a bottom view) and a tangent line of the curved line indicating the pressure surface **53** at a point where the outer circumferential edge and the curved line indicating the pressure surface **53** are in contact with each other, and is 90° or less. The term "camber angle" is an angle which is formed by a line connecting the leading edge of a blade **51** and the rotation axis of the impeller **30**, and a line connecting the trailing edge of the corresponding blade **51** and the rotation axis as seen in a bottom view.

The shape of each pressure surface **53** is determined, for example, as follows. That is, the sizes of the inner circumferential edge and the outer circumferential edge are determined according to design specifications, the size of the motor, and so on. In view of the design specifications and reducing the level of noise such as NZ sound, the inlet angle, the outlet angle, and the camber angle are determined. Therefore, as seen in the bottom view, first to fourth points which the pressure surface **53** passes are determined. That is, as shown in FIG. **7**, a first point P1 indicates the position of the trailing edge, and becomes the vertex of the outlet angle. A fourth point P4 indicates the position of the leading edge, and becomes the vertex of the inlet angle. A second point P2 is the intersection of a first circle C2 which is concentric with a circle C1 indicating the outer circumferential edge and has a size of ¾ of the size of the circle C1, and a straight line L2 that forms an angle A2 of 3⁄10 of the camber angle with respect to a straight line L4 extending from the rotation axis to the fourth point P4. A third point P3 is the intersection of a second circle C3 that is concentric with the first circle C2 and is positioned between the first circle C2 and a circle C4 indicating the inner circumferential edge, and the straight line L4 that forms an angle A3 of 3⁄20 of the camber angle with respect to the straight line L4. Further, the first point P1 and the second point P2, the second point P2 and the third point P3, and the third point P3 and the fourth point P4 are connected by arcs R1, R2, and R3, respectively. In this case, the three arcs R1, R2, and R3 are drawn such that the inlet angle and the outlet angle become predetermined angles, two arcs R1 and R2 connected to each other have a tangent relation (a relation in which the tangent lines of the two arcs at the contact point of the two arcs overlap each other), and two arcs R2 and R3 connected to each other have a tangent relation. In this way, the shape of each pressure surface **53** is determined.

The negative pressure surface **54** has roughly a curved shape following the pressure surface **53** as seen in a bottom view such that a distance from the pressure surface **53** is reduced as increasing a distance from the rotation axis of the impeller **30**. Therefore, each blade **51** has a wing-like outer shape.

As the pressure surface **53** is seen from the direction in which the rotation axis of the impeller **30** extends, the pressure surface **53** may have a shape expressed by combining a plurality of high-dimensional functions passing three points.

That is, in the present illustrative embodiment, the shape of the pressure surface **53** of each blade **51** is formed by three arcs as seen in the bottom view. Therefore, the flow and static pressure of the centrifugal fan can be improved and noise of the centrifugal fan can be reduced.

In the present illustrative embodiment, the thickness of each blade **51**, that is, the distance between the pressure surface **53** and negative pressure surface **54** of each blade **51** is reduced as increasing a distance from the upper shroud **31** in a direction parallel to the rotation axis. In other words, each blade **51** is formed to become thinner as it approaches the partition portion **29**. Therefore, the distance between the pressure surface **53** of a blade **51** and the negative pressure surface **54** of another blade **51** next to the corresponding blade **51** increases as they approach the partition portion **29**.

FIG. **8** is a view schematically illustrating a cross section of the blade **51**.

The cross section shown in FIG. **8** is a cross section which is perpendicular to a horizontal plane perpendicular to the rotation axis and is substantially perpendicular to the pressure surface **53** as seen in a bottom view. That is, the cross section shown in FIG. **8** corresponds to a cross section along the line C-C of FIG. **5**. In FIG. **8**, hatching is omitted. An arrow Z indicates a direction (upper side) parallel to the rotation axis of the impeller **30**.

The pressure surface **53** is away from the negative pressure surface **54** in a direction of approaching the outer circumferential side of the blade **51** (the left side in FIG. **8**) as it approaches the upper shroud **31**. In other words, each blade **51** has the pressure surface **53** which is inclined to be tapered. Over the entire area of every blade **51** from the inner side to the outer side, a pressure surface **53** is formed in that tapered shape.

In FIG. **8**, an angle θ represents the inclination, that is, a taper angle of the pressure surface **53** with respect to the rotation axis of the impeller **30**. The taper angle θ is set to, for example, about 4° to 8°. In each blade **51**, the negative pressure surface **54** is substantially parallel to the rotation axis in a cross section as shown in FIG. **8**. That is, each negative pressure surface **54** is formed to become a plane perpendicular to a horizontal plane perpendicular to the rotation axis of the impeller **30**. The lower end portion of each blade **51** is substantially horizontal (parallel to a plane perpendicular to the arrow Z of FIG. **8**) in the cross section shown in FIG. **8**. Therefore, each blade **51** has a trapezoidal shape in a cross section as shown in FIG. **8**.

Since the blades **51** are formed as described above, the noise level can be reduced while securing a high static pressure, as compared to a case where the taper angle of every pressure surface **53** is 0° (that is, there is no taper angle). Also, in every blade **51**, a taper angle as described above may not be set.

[Description of Step Portions of Blade **51**]

In the present illustrative embodiment, in each blade **51**, stepped portions **57** and **58** (examples of discontinuous portions) are formed at the pressure surface **53** and the negative pressure surface **54**, respectively.

FIG. **9** is a perspective view illustrating the bottom side of the impeller **30**. FIG. **10** is a perspective view illustrating the top side of the impeller **30**.

As shown in FIG. **9**, the pressure surface **53** of each blade **51** is formed with a first stepped portion **57** at a side of the leading edge portion **51***a* of the corresponding blade **51**. Also, as shown in FIG. **10**, the negative pressure surface **54** is formed with a second stepped portion at the side of the leading edge portion **51***a*. That is, in the present illustrative embodiment, the pressure surface **53** and the negative pressure surface **54** each have a step shape of one step at the first stepped portion **57** and the second stepped portion **58**. That is, the pressure surface **53** and the negative pressure surface **54** each have a shape which is partially not smooth or continuous (hereinafter, also referred to as a discontinuous shape) at the first stepped portion **57** and the second stepped portion **58**.

FIG. **11** is a cross-sectional view taken along the line G-G of FIG. **4**.

A cross section shown in FIG. **11** is a cross section in a plane which is perpendicular to the rotation axis of the impeller **30** and passes the leading edge portions **51***a* of the blades **51**, that is, the contact points of the blades **51** with the lower shroud **41**. As shown in FIG. **11**, the first stepped portions **57** of the blades **51** are formed at positions which are the same in the distance from the rotation axis of the impeller **30**. Similarly, the second stepped portions **58** of the blades **51** are also formed at positions which are the same in the distance from the rotation axis of the impeller **30**.

In each blade **51**, the first stepped portion **57** and the second stepped portion **58** are formed at positions included in a predetermined range close to the leading edge portion **51***a*. More specifically, the first step portion **57** and the second step portion **58** are formed at positions as follow. That is, the diameter of an inner circumferential circle C11 of the blades **51** passing the rotation axis of the impeller **30** through the leading edge portions **51***a* of the blades **51** is referred to as an inside blade diameter d. The diameter of an outer circumferential circle C12 of the blades **51** passing the rotation axis of the impeller **30** through the trailing edge portions **51***b* is referred to as an outside blade diameter D. In a cross section passing though the leading edge portions **51***a* shown in FIG. **11**, the inner circumferential circle C11 and the outer circumferential circle C12 are substantially matched with the circle C4 and the circle C1 shown in FIG. **7**, respectively.

In the present illustrative embodiment, with respect to each of the first stepped portion **57** and the second stepped portion **58**, the diameter r (stepped position) of a circle having the rotation axis of the impeller **30** as its center and passing through the corresponding stepped portion is within a range represented by the following expression.

$$d<r<d+(D-d)\times 0.4$$

That is, each of the first stepped portion **57** and the second stepped portion **58** is positioned within a range extending in a radial direction perpendicular to the rotation axis between the leading edge portions **51***a* and a predetermined distance outward of the leading edge portions in the radial direction (a range which is on the inner side than a circle C13). Here, the predetermined distance is a distance which is 40% of a distance from the leading edge portion **51***a* to the trailing edge portion **51***b* in the radial direction of the impeller **30**.

FIG. **12** is an enlarged view of a portion of FIG. **11**.

As shown in FIG. **12**, the first stepped portion **57** and the second stepped portion **58** are formed such that in the shape of the blade **51**, the thickness of the blade suddenly changes at those portions whereby stepped portions are formed at the pressure surface **53** and the negative pressure surface **54**, respectively. In the present illustrative embodiment, stepped portions are formed such that, with each of the first stepped portion **57** and the second stepped portion **58** as a border, the thickness at a side of the trailing edge portion **51***b* becomes suddenly larger than the thickness at a side of the leading edge portion **51***a*.

Each of the first stepped portion **57** and the second stepped portion **58** is formed, for example, such that a step is formed along the rotation axis direction of the impeller **30**. In other words, each of the first stepped portion **57** and the second stepped portion **58** is a step substantially parallel to the rotation axis of the impeller **30**. Therefore, the impeller **30** can be formed comparatively easily. That is, a mold having a comparatively simple structure can be used as a mold for forming the impeller **30**.

In the present illustrative embodiment, since the stepped portions **57** and **58** are formed as described above, during rotation of the impeller **30**, generation of a vortex in each blade **51**, which causes generation of noise and reduction of efficiency, can be reduced. That is, since the first stepped portions **57** and the second stepped portions **58** are formed, during an operation of the centrifugal fan **1**, noise is reduced, and the efficiency is improved.

FIG. **13** is a view illustrating a vortex generation area on a side of the pressure surface **53** during rotation of the impeller **30**. FIG. **14** is a view illustrating a vortex generation area on a side of the negative pressure surface **54** during rotation of the impeller **30**. FIG. **15** is a view illustrating a vortex generation area on a side of the pressure surface **53** in an impeller without the stepped portions **57** and **58**. FIG. **16** is a view illustrating a vortex generation area on a side of the negative pressure surface **54** in the impeller without the stepped portions **57** and **58**.

In FIGS. **13** to **16**, there are shown the results obtained by performing simulations, with respect to air vortexes which are generated around the impeller **30** in a case where blowing is performed by the impeller **30**, under the same condition. In FIGS. **13** to **16**, portions shown in gray represent generated vortexes. FIGS. **13** and **14** show the blades **51** with the stepped portions **57** and **58** according to the present illustrative embodiment. On the other hand, FIGS. **15** and **16** show blades **651** without the stepped portions **57** and **58**, as a comparative example.

From comparison between FIG. **13** and FIG. **15**, it can be appreciated that in the present illustrative embodiment, since the first stepped portions **57** are formed at the pressure surfaces **53**, generation of vortexes is reduced, especially, on the downstream sides (sides close to the trailing edge portions **51***b*) of the first stepped portions **57**, and separation of the flow of air is unlikely to occur. Similarly, from comparison between FIG. **14** and FIG. **16**, it can be appreciated that since the second stepped portions **58** are formed at the negative pressure surfaces **54**, generation of vortexes is reduced, especially, on the downstream sides of the second stepped portions **58**.

Also, referring to FIG. **15**, in a case where pressure surfaces **53** have no first stepped portions **57**, at positions away from the leading edge portions **51***a* by more than 40%

in the radial direction of the impeller **30** as seen in a bottom view, generation of vortexes can be seen (an area shown by a reference symbol "V" in FIG. **15**). That is, in each pressure surface **53**, in an area from an arc C13 to an arc C12 as seen in a bottom view, a vortex is likely to be generated. Therefore, if a first stepped portion **57** is formed within an area in front of the area from the arc C13 to the arc C12, that is, a range which is closer to the leading edge portion **51***a* than a position which is 40% of a direction from the leading edge portion **51***a* to the trailing edge portion **51***b* in the radial direction of the impeller **30** (a position shown by the arc C13) is, generation of vortexes can be efficiently reduced. Even in the negative pressure surface **54**, since a vortex is likely to be generated in the same area, if a second stepped portion **58** is formed within a range which is closer to the leading edge portion **51***a* than the position which is 40% of the direction from the leading edge portion **51***a* to the trailing edge portion **51***b* in the radial direction of the impeller **30** is, generation of vortexes can be efficiently reduced.

FIG. **17** is a graph illustrating the level of noise of the centrifugal fan **1**.

FIG. **17** shows the measured results of noise occurring during driving of the centrifugal fan **1** in comparison with the measured results of noise occurring during driving of a centrifugal fan without the stepped portions **57** and **58** (a comparative example). From the graph, it can be appreciated that in the centrifugal fan **1** according to the present illustrative embodiment, except for a frequency range in which the frequency is high, the noise level is lower than that of the comparative example in a wide frequency range which is normally used. Especially, a reduction in the noise level in a low-speed rotation range in which the noise level is comparatively high is remarkable. When overall values of noise character diagrams are compared, in the centrifugal fan **1**, an effect of reducing the noise level by 1.2 dBA with respect to the comparative example is obtained.

FIG. **18** is a diagram illustrating the P-Q curve of the centrifugal fan **1**.

FIG. **18** shows the P-Q curve of each of the centrifugal fan **1** and the centrifugal fan without the stepped portions **57** and **58** (the comparative example). As can be seen from the graph, almost over the entire range from when the flow is maximum to when the static pressure is maximum, the centrifugal fan **1** according to the present illustrative embodiment has a characteristic better than that of the comparative example. That is, it can be said that the centrifugal fan **1** has higher efficiency.

As described above, in the present illustrative embodiment, at every blade **51** of the centrifugal fan **1**, the stepped portions **57** and **58** are formed. As a result, the efficiency of the centrifugal fan **1** and reduce noise can be improved. Therefore, noise of a product using the centrifugal fan **1** can be reduced. This centrifugal fan **1** can be widely applied, especially, to products requiring suction cooling (for example, appliances, personal computers, office automation equipment, in-car devices, etc.).

The stepped portions **57** and **58** are disposed at positions capable of effectively suppressing vortexes from occurring around the blades **51** as described above. Therefore, the efficiency of the centrifugal fan **1** can be effectively improved.

In the centrifugal fan **1**, for the pressure surface **53** of every blade **51**, the taper angle is set such that the pressure surface **53** has a tapered shape. Since every pressure surface **53** is formed in a tapered shape, in the centrifugal fan **1** using the impeller **30**, the maximum static pressure can be increased, and generation of noise can be suppressed. Therefore, the centrifugal fan **1** can be made thin, highly-efficient, and low-noise.

In each blade **51**, the pressure surface **53** is configured by combination of three or more arcs as seen in a bottom view, or the curves of high-dimensional functions. Therefore, an efficient blade shape following the flow of air can be made, which has an effect of causing an increase in flow, an increase in static pressure, and a reduction in noise.

[Description of Modifications]

Also, instead of the step shape as in the first stepped portions **57** and second stepped portions **58**, discontinuous portions having other step shapes such as grooves each of which is composed of a plurality of steps may be formed. Also, each discontinuous portion may be composed of a plurality of steps or grooves. These discontinuous portions may be formed on the side of the leading edge portion **51***a* of at least one of the pressure surface **53** and the negative pressure surface **54** of each blade **51**. That is, since separation of the flow of a fluid is unlikely to occur on the surfaces having the discontinuous portions, the same effects as described above can be obtained.

The discontinuous portions may be formed such that the pressure surfaces **53** and the negative pressure surfaces **54** undulate along a direction parallel to the rotation axis of the impeller **30**. Then, a mold for forming the impeller **30** can be made in a simple structure, and the impeller **30** can be easily formed. For example, the mold of two separate structures of a movable side and a fixed side can be employed.

FIG. **19** is a perspective view illustrating an impeller of a centrifugal fan **1** according to a first modification of the present illustrative embodiment. FIG. **20** is a view illustrating the blade shape of the impeller of the centrifugal fan **1** according to the first modification.

As shown in FIG. **19**, the basic structure of an impeller **130** is the same as that of the above described impeller **30**. In the impeller **130**, instead of the blades **51** with the stepped portions **57** and **58**, blades **151** having groove portions (examples of the discontinuous portions) **157** and **158** (first groove portions **157** and second groove portions **158**) are provided.

FIG. **20** shows a cross section of the impeller **130** at the same plane as that of FIG. **11**. As shown in FIG. **20**, the groove portions **157** and **158** are formed at the pressure surfaces **53** and the negative pressure surfaces **54**, respectively, and each includes three grooves. In the first modification, the grooves of each blade **151** are formed at substantially regular intervals from the vicinity of the leading edge portion **51***a* toward the trailing edge portion **51***b*. Since the groove portions **157** and **158** are formed, the pressure surfaces **53** and the negative pressure surfaces **54** become discontinuous.

Since the groove portions **157** and **158** are formed as described above, the same effects as described above can be obtained. That is, due to the action of the groove portions **157** and **158**, separation of the flow of a fluid becomes unlikely to occur around the blades **151**. Therefore, even in the centrifugal fan **1** having the above described impeller **130**, high efficiency and low noise can be achieved.

FIG. **21** is a perspective view illustrating an impeller of a centrifugal fan **1** according to a second modification of the present illustrative embodiment. FIG. **22** is a view illustrating the blade shape of the impeller of the centrifugal fan **1** according to the second modification.

As shown in FIG. **21**, the basic structure of an impeller **230** is the same as that of the above described impeller **30**.

In the impeller **230**, instead of the blades **51** having the stepped portions **57** and **58**, blades **251** having stepped portions (examples of the discontinuous portions) **257** and **258** (first stepped portions **257** and second stepped portions **258**) are provided.

FIG. **22** shows a cross section of the impeller **130** in the same plane as that of FIG. **11**. As shown in FIG. **22**, the stepped portions **257** and **258** are formed at the pressure surfaces **53** and the negative pressure surfaces **54**, respectively, and each includes two steps. In the second modification, the steps of each blade **151** are formed such that the thickness of the corresponding blade **251** increases in a stepwise manner from the vicinity of the leading edge portion **51***a* toward the trailing edge portion **51***b*. Since the stepped portions **257** and **258** are formed, the pressure surfaces **53** and the negative pressure surfaces **54** become discontinuous.

Since the stepped portions **257** and **258** are formed as described above, the same effects as described above can be obtained. That is, due to the action of the stepped portions **257** and **258**, separation of the flow of a fluid becomes unlikely to occur around the blades **151**. Therefore, also in the centrifugal fan **1** having the above described impeller **230**, high efficiency and low noise can be achieved.

Also, as described above, in each of the blades **51**, **151**, and **251**, a pressure surface **53** is formed in a tapered shape, and in the first stepped portions **57** and **257** and the first groove portions **157**, the steps and the grooves may be formed along the surfaces of the pressure surfaces **53**. On the other hands, the first stepped portions **57** and **257**, and the first groove portions **157** may be formed such that the heights of the steps or the depths of the grooves from the surfaces of the pressure surfaces **53** change along the rotation axis direction. Even in both cases, high efficiency and low noise of the centrifugal fan **1** can be obtained, and the impellers **30**, **130**, and **230** can be formed.

[Others]

The discontinuous portions such as the step portions and the groove portions do not necessarily need to be formed both sides of the pressure surface side and the negative pressure surface side. For example, the discontinuous portions may be formed only on the pressure surface side, or only on the negative pressure surface side.

The number of steps or grooves which are formed in each discontinuous portion is counted from the leading edge portion to the trailing edge portion, and may be one or more. Also, at each pressure surface or negative pressure surface, as a discontinuous portion, one or more steps and one or more groove portions may be formed side by side.

The blades are not limited to blades having pressure surfaces having a tapered shape. Each pressure surface may have a tapered shape only at a portion of an area from the inner side to outer side of each blade. Also, in the lower end portion (partition-portion-side portion) of each blade, the pressure surface may become substantially perpendicular to a horizontal plane, similarly to the negative pressure surfaces, and only a portion of the pressure surface close to the upper shroud may have a tapered shape. Also, only in some blades of the plurality of blades, each pressure surface may have a tapered shape.

The pressure surface of each blade is not limited to the tapered shape as linearly shown in a cross section as shown in FIG. **8** described above. For example, each pressure surface may be formed so as to approach a corresponding negative pressure surface as it approaches the partition portion, while being slightly curved in a cross section as described above.

The rough shape of the pressure surface of each blade as seen in a bottom view may not be a shape in which three arcs are connected as described above, and may not be a shape expressed by a combination of high-dimensional functions passing three points. The blades need only to be formed in an appropriate shape satisfying a desired condition.

The negative pressure surfaces may not be formed to be substantially perpendicular to a horizontal plane as described above. For example, the negative pressure surfaces may be slightly inclined, like the pressure surfaces.

The shape of the casing is not limited to a substantially square shape as seen in a plan view. The casing may have any arbitrary shapes such as a polygonal shape, a circular shape, and an asymmetric shape. The fastening portions of the upper casing and the lower casing are not limited to the insides of four corners of the upper casing as seen in a plan view. For example, at portions connected to protrude outward from the outer peripheral edge forming a substantially square shape as seen in a plan view of the upper casing, screws, supports, and the like for assembling the upper casing and the lower casing may be provided.

Also, in a case where supports are provided between the upper casing and the lower casing at the portions for fastening the upper casing and the lower casing, the shapes of the supports may be, for example, as follow. That is, the supports may have a substantially cylindrical shape having a size allowing screws for joining the upper casing and the lower casing to pass through. If supports having a shape as described above are used, air expelled from the impeller is expelled outward from the sides of the casing, with little or no resistance. Therefore, noise of a centrifugal fan can be reduced.

The lower casing may be formed by using materials such as a resin material other than a metal plate. The upper casing and the lower casing may be formed integrally.

It should be noted that the above-mentioned illustrative embodiment is merely illustrative in all aspects and are not to be construed as limiting the invention. The scope of the invention is defined by the appended claims rather than the detailed description of the invention. All changes or modifications or their equivalents made within the meanings and scope of the claims should be construed as falling within the scope of the invention.

What is claimed is:

1. A centrifugal fan comprising:

an impeller rotatable about a rotation axis; and

a lower casing which is provided below the impeller,

wherein the impeller includes an upper shroud having an upper portion formed with an inlet, a lower shroud, and a plurality of blades arranged along a circumference direction between the upper shroud and the lower shroud, and a fluid introduced from the inlet is discharged to a side of the impeller according to rotation of the impeller,

wherein the blades extend from an inner side area to an outer side area in a radial direction, and the blades are only connected to the lower shroud with the inner side area of the blades such that at least an outer circumferential side portion of each blade faces an upper surface of the lower casing,

wherein a surface of the lower casing, which faces the impeller, configures a portion of a wall surface which guides the fluid introduced from the inlet,

wherein a surface of each blade is formed with a discontinuous portion having a step shape, the discontinuous portion being disposed closer to a leading edge portion of the blade than to a trailing edge portion of the blade, wherein each blade has a pressure surface and a negative pressure surface, the pressure surface being directed to a leading side of the impeller, the negative pressure surface being directed to a side opposite from the leading side to which the pressure surface is directed,

wherein the pressure surface is inclined to be tapered toward the negative pressure surface at a constant taper angle, and

wherein a distance between the pressure surface and the negative pressure surface is gradually decreased in a direction from the upper shroud to the lower casing.

2. The centrifugal fan according to claim **1**, wherein the discontinuous portion is formed on at least one of the pressure surface and the negative pressure surface of each blade.

3. The centrifugal fan according to claim **1**, wherein the step shape of the discontinuous portion is formed along a direction substantially parallel to the rotation axis.

4. The centrifugal fan according to claim **1**, wherein the discontinuous portion includes at least one of one or more step shapes and one or more groove shapes.

5. The centrifugal fan according to claim **1**, wherein the discontinuous portion is formed within a range extending in a radial direction perpendicular to the rotation axis between the leading edge portion and a predetermined distance outward of the leading edge portion in the radial direction, and

wherein the predetermined distance is 40% of a distance from the leading edge portion to the trailing edge portion of each blade in the radial direction.

6. The centrifugal fan according to according to claim **1**, wherein as seen from a direction in which the rotation axis of the impeller extends, the pressure surface of each blade has a shape in which at least three arcs are connected, or a shape expressed by a combination of a plurality of high-dimensional functions passing three points.

7. The centrifugal fan according to claim **1**, further comprising:

a motor which is attached to the lower shroud and configured to rotate the impeller to introduce the fluid from the inlet and discharge the fluid to the side of the impeller.

8. The centrifugal fan according to claim **2**, wherein the discontinuous portion is formed on both of the pressure surface and the negative pressure surface of each blade.

9. The centrifugal fan according to claim **8**,

wherein the discontinuous portion formed on each of the pressure surface and the negative pressure surface includes one or more step shapes or one or more groove shapes,

wherein a number of the step shapes or the groove shapes formed on the pressure surface is equal to a number of the step shapes or the groove shapes formed on the negative pressure surface.

10. The centrifugal fan according to claim **1**, wherein a height of the step shape of the discontinuous portion is constant along a direction parallel to the rotation axis.

11. The centrifugal fan according to claim **1**, wherein a height of the step shape of the discontinuous portion changes along a direction parallel to the rotation axis.

12. The centrifugal fan according to claim **1**, wherein an outer circumferential end portion of the lower shroud is positioned in a vicinity of an inner circumferential end portion of the upper shroud as viewed in a direction parallel to the rotation axis.

13. An impeller rotatable about a rotation axis, the impeller comprising:

an upper shroud having an upper portion formed with an inlet;

a lower shroud; and

a plurality of blades arranged along a circumference direction between the upper shroud and the lower shroud,

wherein the blades extend from an inner side area to an outer side area in a radial direction, and the blades are only connected to the lower shroud with the inner side area of the blades such that at least an outer circumferential side portion of each blade is exposed,

wherein a surface of each blade at a side of a leading edge portion is formed with a discontinuous portion having a step shape,

wherein each blade has a pressure surface and a negative pressure surface, the pressure surface is directed to a leading side of the impeller, the negative pressure surface being directed to a side opposite from the leading side to which the pressure surface is directed,

wherein the pressure surface is inclined to be tapered toward the negative pressure surface at a constant taper angle, and

wherein a first distance between the pressure surface and the negative pressure surface is gradually decreased as a second distance from the upper shroud in a direction parallel to the rotation axis of the impeller is increased.

14. The centrifugal fan according to claim **1**, wherein the constant taper angle of the pressure surface with respect to the rotation axis of the impeller is set between 4 degrees and 8 degrees.

15. The impeller according to claim **13**, wherein the constant taper angle of the pressure surface with respect to the rotation axis of the impeller is set between 4 degrees and 8 degrees.

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